VOLUME 18, 1956/57, No. 8 pp. 217-248 Published 4th February 1957

Philips Technical Review

DEALING WITH TECHNICAL PROBLEMS
RELATING TO THE PRODUCTS, PROCESSES AND INVESTIGATIONS OF
THE PHILIPS INDUSTRIES

EDITED BY THE RESEARCH LABORATORY OF N.V. PHILIPS' GLOEILAMPENFABRIEKEN, EINDHOVEN, NETHERLANDS

PROBLEMS IN THE CONSTRUCTION OF SMALL RADIO VALVES

by B. A. CANT *).

621.385.1-181.4:621.396.694

In the last 20-25 years radio valves have been made smaller and smaller. The sub-miniature types, evolved for use in portable apparatus, supplied by battery, are extremely small. Although the advent of the transistor in the last few years has meant the replacement of these valves in some fields of application, there remain many instances in which the transistor cannot yet be substituted for the radio valve. In this article the author will deal with some of the problems encountered in the construction of valves of very small dimensions.

Introduction

The earliest radio valves were used in rather bulky receivers, so that their size was immaterial. With the increasingly higher demands imposed upon valves, the dimensions of newly developed types became smaller and smaller. This trend has often been described in this Review [1]). It is particularly apparent in the domain of battery-fed valves, used predominantly in portable sets, for which small dimensions and light weight are prime considerations. Whereas the envelope of a battery-fed valve such as the KF 3 had a diameter of 40 mm, this dimension is only 19 mm for valves like the DF 96 and DF 97. The two latter belong to the series of so-called *miniature valves*. More recently valve dimensions were even further reduced in a series of *sub-miniature valves* (*fig. 1*), which found application in hearing aids [2]), for example. The rapid development of the transistor has diminished the importance of valve-equipped hearing aids, but nevertheless large numbers of these units are still in use. Sub-miniature valves are also used in other equipment, such as radio sondes [3]) and small portable transceivers (walkie-talkies). For many functions in such equipments, radio valves can as yet not be replaced by transistors, mainly owing to the fact that valves can be used at higher frequencies than currently available transistors.

In this article we shall deal with some of the problems in the construction of miniature and sub-miniature valves that have claimed particular attention. Since we are nearly always concerned with valves for battery supply, we shall also pay attention to the various measures taken to reduce their current consumption to a minimum.

Shape and dimensions of the envelope

The construction of the first receiver valves was simply modelled on the incandescent lamp. The electrodes were housed in a fairly large glass bulb, and a number of lead-in wires, held together in a pinch, formed the connection to the electrodes. *Fig. 2a* shows how the bulb of such a valve with pinch construction was sealed off. The valves were then finished off by fitting them with a bakelite base with pressed-in contacts. The drawbacks of this construction have been pointed out in the articles quoted in [1]). In a later type, of "all-glass" con-

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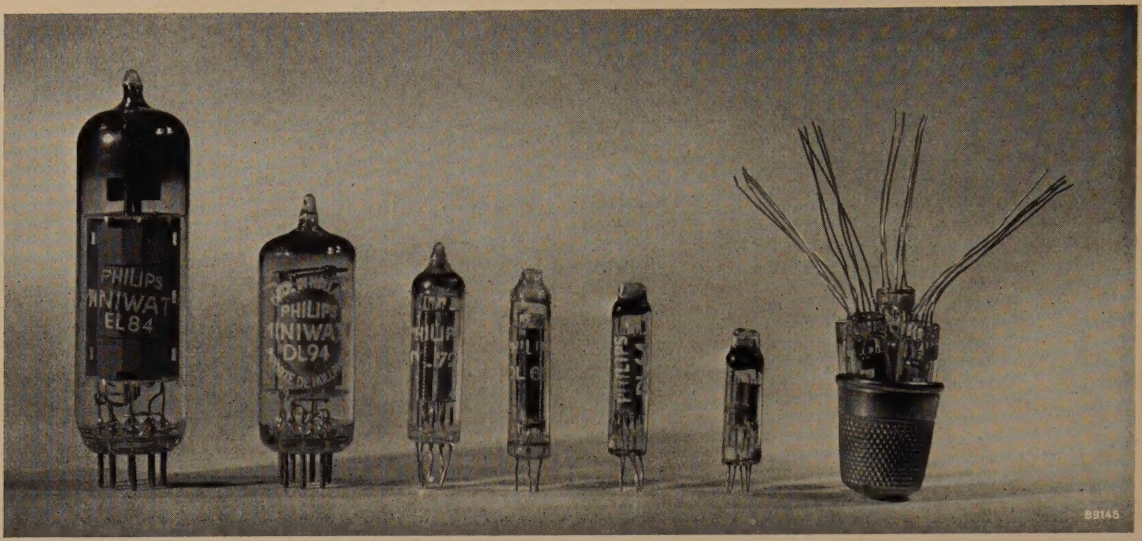
*) The Mullard Radio Valve Co., Ltd., Mitcham, England.

[1]) P. G. Cath, A new principle of construction for radio valves, Philips tech. Rev. **4**, 162-166, 1939. Th. P. Tromp, Technical problems in the construction of radio valves, Philips tech. Rev. **6**, 317-323, 1941. G. Alma and F. Prakke, A new series of small radio valves, Philips tech. Rev. **8**, 289-295, 1946. J. L. H. Jonker, Electron tubes, Philips tech. Rev. **14**, 117-128, 1952/53.

[2]) Cf. P. Blom, An electronic hearing aid, Philips tech. Rev. **15**, 37-48, 1953/54.

[3]) See A. Hauer and M. van Tol, A radio sonde for meteorological observations, Philips tech. Rev. **16**, 148-156, 1954/55.



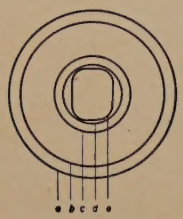


Fig. 1. Some sub-miniature valves compared with two larger valves. The photo shows from the left to the right: an indirectly-heated power amplifier pentode (EL 84), a miniature valve (DL 94), the round sub-miniature valves DL 72 (diameter 10 mm) and DL 65 (diameter 7.9 mm), the flat sub-miniature valves DL 64 and DF 64, and finally four DL 64 valves fitted in a thimble.

The inset sketch shows the bulb cross-sections of these valves, drawn full size. *a*) EL 84 (diameter 22 mm), *b*) DL 94 (19 mm), *c*) DL 72 (10 mm), *d*) DL 65 (7.9 mm), *e*) DL 64 and DF 64 (7.25 × 5.6 mm).

struction, both cap and pinch were eliminated, and this considerably improved the performance of the valve in several respects. The dimensions of the valves manufactured on this principle became smaller and smaller. The envelope diameter of the miniature valves, as mentioned earlier, was 19 mm. A subsequently developed "all-glass" series, the *round* sub-miniature valves, had a diameter of only 10 mm, and even 7.9 mm for some types.

With miniature and round sub-miniature valves, like the older "all-glass" valves, the electrode assembly is mounted on a number of pins sealed into a glass plate; the latter, on being sealed to the envelope, forms the base of the valve. Figs. 2*b* and *c* show the method of sealing-in. Because of the small dimensions, the electrodes are close to the sealing joint and run the risk of becoming so hot during the sealing process that they are liable to mechanical or chemical damage. This risk is even greater for another series of valves, developed by some manufacturers round about the same time as the round sub-miniature valves. Here the envelope is of a rectangular cross-section (some types having dimensions of 7.25×5.6 mm) which, for rectangular or oval-shaped electrodes, makes possible a more efficient use of the space available in the envelope. Sealing of the envelope is effected by pressing its outer edges together over the connecting wires, the latter being arranged in a single plane (fig. 2*d*). Here, in fact, we once again have the pinch type of construction with its attendant drawbacks. Indeed, owing to the small dimensions and to the different manufacturing procedure, some difficulties are encountered that were either absent or present to a much slighter degree in the older valves with pinch construction. Whereas with the old valves the pinch was made before the electrodes were connected to the lead-in wires, with subminiature valves the operation is not performed until the whole electrode assembly has been completed and mounted on the connecting wires. Since during sealing-off the glass is heated up to 800-900 °C, there is a considerable risk of the electrodes being subjected to inadmissibly high temperatures. The danger is greatest for the cathode, whose emissive power may be gravely impaired by excessive heating during sealing-off. It will be clear that, with a construction in accordance with figs. 2*b* and *c*, the electrodes are far less liable to excessive heating.

Another disadvantage of the construction of fig. 2*d* is that the lead-in wires have to be fixed at definite intervals and in the same plane whilst being sealed into the envelope. This difficulty does not occur with a construction where the lead-in pins are fixed in a glass base plate before the electrodes are mounted and before sealing-in, as in the miniature and round sub-miniature valves.

In a new series of sub-miniature tubes it has been found possible to combine the advantages of an envelope of rectangular section with those of electrode mounting on a flat base plate. The latter is oval in shape and contains, like that of the miniature and round sub-miniature valves, the lead-in wires on which the electrodes are mounted before the valve is sealed-off.

Some additional provisions are made to prevent overheating of the electrodes during sealing-off. The envelope, for instance, is placed with the base plate on top, and a stream of an inert gas is blown through the envelope during sealing. The rim of the base plate is kept as thin as possible, so that a short heating time will be sufficient. The gas jets, moreover, are of such a shape and size that heating is strictly localized, whilst penetration of the flames into the envelope is prevented by giving the latter a cup-shaped extremity which accurately fits round the base plate.

Since with this sealing method the cathode is far less liable to overheating, it was found possible to manufacture "rectangular" or "flat" sub-miniature valves with a thinner filament than could be achieved with the pinch construction. Filament-current consumption can thus be substantially reduced.

The filament

In the earliest type of radio valves tungsten was used for the (directly heated) filament. Later nickel containing a small proportion of other elements was used, both for directly and indirectly heated cathodes, as it forms a better basis for the emissive oxide layer that has to be deposited on the cathode. The endeavour to restrict the filament current of battery-fed valves to the barest minimum, however, necessitated a return to tungsten as filament material. The fairly low tensile strength of nickel wire did not permit the manufacture of wire thinner than 22-24 μ. Tungsten wire, having a greater tensile strength, has been manufactured in filaments of only 6.3 μ for use in some sub-miniature valves, making it possible to reduce their filament current to about 10 mA. Another article in this issue [4]) gives further particulars regarding the manufacture of very thin wires of this kind.

The choice of filament diameter is closely connected with the desired temperature. Where battery-fed valves are concerned, several factors must be considered in determining the optimum temperature. At too high a temperature the valve will operate better to start with, but at the sacrifice of

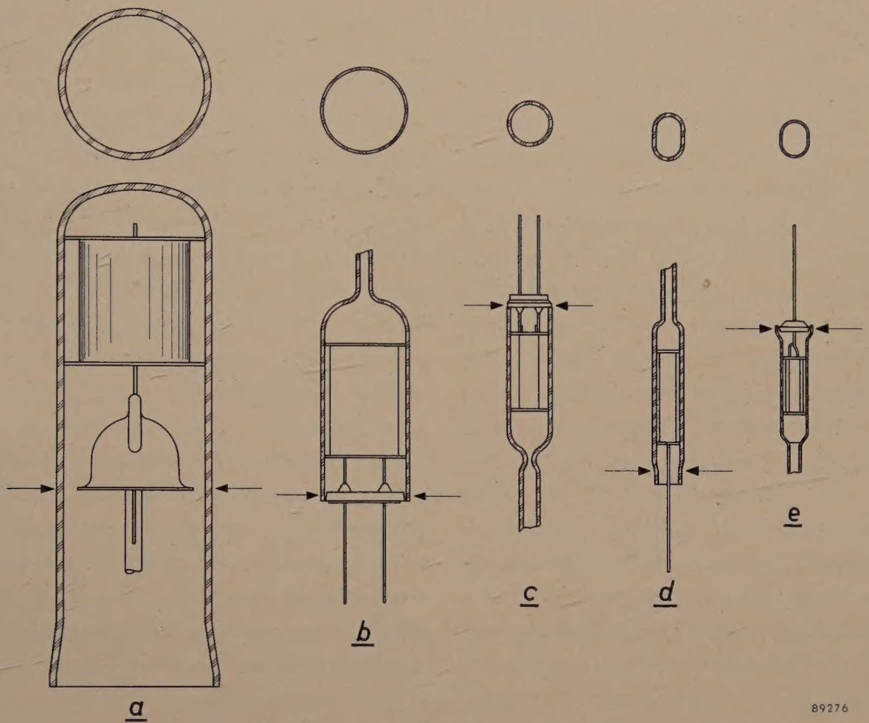


Fig. 2. Methods of sealing-in of various types of electronic valves. The arrows show how the gas flames are applied.
a) Earlier valve types with pinch construction.
b) Miniature valves; glass base.
c) Round sub-miniature valves; glass base.
d) Flat sub-miniature valves with pinch construction.
e) Flat sub-miniature valves with flat glass base.

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[4]) L. Schultink and P. G. van Zanten, Thin tungsten wire for small radio valves, Philips tech. Rev. **18**, 222-228, 1956/57 (No. 8).

its service life. Too low a temperature has the great drawback that the valve properties are unduly affected by the battery voltage. Particularly in battery-fed valves, the filament voltage may drop appreciably below the rated value, and it is naturally desirable that the valves should continue to operate properly even in these conditions.

If in a valve the filament current is not large with respect to the emission current of the cathode, the filament temperature is affected by the latter in two ways. Electron emission itself has a cooling effect; furthermore, the cathode emission current flows through only a part of the filament, so that this part of the total filament length develops additional heat. This non-uniform heating of the filament is obviously undesirable and imposes, for a given emission current, a lower limit on the filament current and hence on the filament diameter. It may be assumed that the filament current should be at least eight times the emission current, which means that for a filament current of 10 mA an emission current of at the most 1.25 mA is permissible. It is for this reason that in some sub-miniature valves a filament somewhat thicker than the above-mentioned minimum of 6.3 μ is employed, in order to attain a filament current of 15 mA.

The grids

The grids of sub-miniature valves also present several constructional problems partly due to their small dimensions, but also arising from the fact that the valves have to operate at particularly low voltages [5]).

At a low anode voltage (e.g. 15 V) the shape of the valve characteristics is greatly affected by electrons reflected from the anode [6]). If these electrons are allowed to reach the screen grid, an undesirable drop in the anode current will result. To prevent this, the potential in the plane of the suppressor grid must be given a value such that the reflected electrons cannot pass the suppressor grid. Since, however, the average speed of the reflected electrons is only slightly lower than that of the electrons moving towards the anode, it is difficult to choose the suppressor potential such that only the forward and not the reflected electrons can pass. In addition many of the forward electrons have suffered a change in direction at the screen grid and some will therefore return to the screen grid before reaching the suppressor. In the quest for an acceptable compromise one of the first objects was to ensure the smallest possible deflection of the electrons when passing the screen grid. A condition for this is that the electrostatic field should remain homogeneous up to very near this grid. An improvement can be brought about by reducing the pitch of this grid [7]) and by employing a low screen-grid voltage. The effect of these two measures on the potential distribution is apparent from a number of cross-sections through equipotential planes shown in *fig. 3*.

Now small pitch and low voltage of the screen grid both have their disadvantages. With a small pitch the current to the screen grid may become too great and there is loss in anode slope. For this reason it was necessary to make the screen grid of sub-miniature valves of extremely thin wire. A very low screen-grid voltage can be applied only when the electrode configuration is such that, in spite of the negative bias of the control grid, the average potential in the plane of the latter grid remains sufficiently high, for if the potential throughout the whole plane becomes negative (*fig. 4a*), the anode current is suppressed. The "penetrating effect" of the screen grid voltage through the control

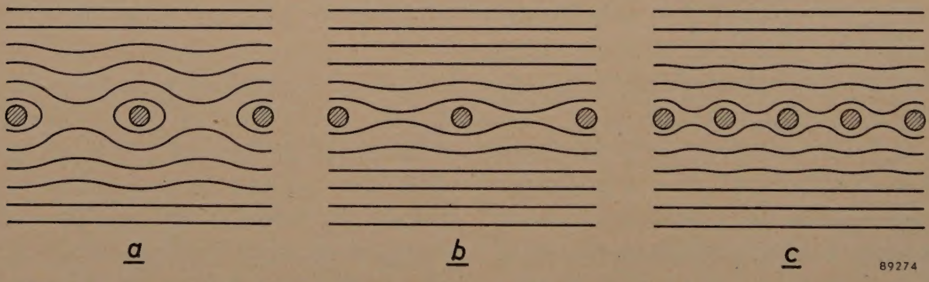

Fig. 3. Cross-sections through some equipotential planes in the vicinity of the screen grid of a pentode. In *b* the screen-grid voltage is lower than in *a*, and in *c* the pitch of the screen grid is lower than in *a*.

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[5]) The lower the voltage of a battery, the higher its energy-volume efficiency, i.e. the more watt.seconds per unit volume.

[6]) See J. L. H. Jonker, Reflections in electron tubes, Philips Res. Rep. 2, 331-339, 1947.

[7]) See J. L. H. Jonker, Electron trajectories in multigrid valves, Philips tech. Rev. 5, 131-140, 1940.

grid, therefore, should be made large, which implies that the amplification factor of the control grid with respect to the screen grid should be made small. This could be achieved by increasing the pitch of the control grid (fig. 4*b*), but this would decrease the slope, which is obviously undesirable. However, it was found possible to retain a sufficiently high slope, and at the same time to maintain a satisfactorily high potential in the plane of the control grid, by using again very thin wire for the winding of the latter (fig. 4*c*).

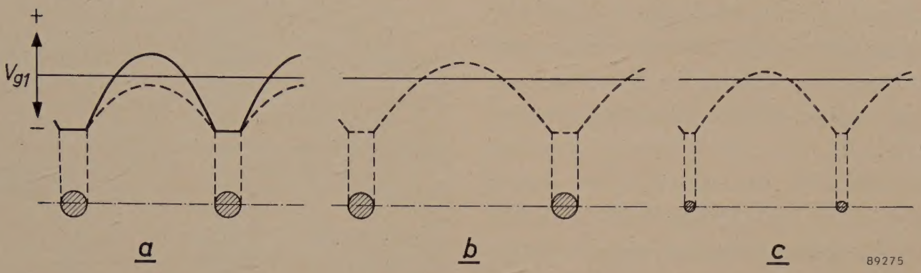

Fig. 4. *a*) The potential in the plane of the control grid. The dotted curve applies to a lower screen-grid voltage than that of the full curve. In the former case the potential in the whole plane is negative.
b) With a larger pitch of the control grid the potential in parts of the control-grid plane may be positive in spite of a low screen-grid voltage.
c) A similar effect is obtainable with thinner grid wires.

For a pentode operating at a very low anode voltage the virtually horizontal part of the I_a-V_a characteristic should preferably extend back as close as possible to the I_a axis. (A valve used as a voltage amplifier then has a high internal resistance, even for a low V_a, whilst for a valve used in an output or power stage, where it must supply a certain power, a characteristic of this type makes for high efficiency.) In achieving this the aim should be to minimize the influence of the anode voltage upon the potential in the plane of the suppressor grid. Giving the suppressor grid a small pitch may be expected to help, but this involves the risk of an inadmissible drop of the average potential in the plane of this grid. This in its turn can be prevented by giving the suppressor grid a moderate positive bias. In some sub-miniature types the suppressor grid is joined to the positive end of the filament for that reason.

Microphony

Since sub-miniature valves are used almost exclusively in small, portable equipments, microphony caused by these valves may be very troublesome. In their design, therefore, special attention should be paid to this problem. As in all other valves with directly heated filaments, the filament itself is the main cause of microphony.

A wire-shaped cathode is not very rigid and will readily vibrate. As a rule this will cause a variation in the grid-cathode spacing and consequently a variation in some of the quantities having an important effect on the working of the valve, such as anode current, slope and input capacitance. In a receiver the loudspeaker may convert these variations into air vibrations, either audible or not, which in their turn may react on the valve. In serious cases vibrations thus set up will be maintained as a form of positive acoustic feedback. In less serious cases any knocks against the set can be heard as a damped vibration of the filament.

The intensity of microphony depends on the amplitude of the vibrating cathode. In a valve of symmetrical construction the effect is somewhat compensated by the fact that an increase in distance at one side is accompanied by a decrease at the other side. An exactly symmetrical arrangement of the electrodes, therefore, is essential to combat microphony.

The resonance frequency of a stretched wire is given by

$$f = \frac{1}{2L}\sqrt{\frac{T}{M}},$$

where L is the length of the wire, T the tension, and M the mass of the wire per unit length.

A high resonant frequency (e.g. above 5000 c/s) is desirable for the following reasons:

a) The initial amplitude of the damped vibration of the wire resulting from a given impact is inversely proportional to the resonance frequency.

b) The feedback of sound vibrations from loudspeaker to cathode is weaker at higher frequencies.

c) Very high notes are less audible than those of medium pitch.

d) The frequency range of an amplifier or of the audio stage of a radio receiver is limited. If the resonance frequency of the valve filaments lies above this range, there is but little risk of acoustic feedback.

With a view to combating microphony, therefore, T/M should be made as large as possible. However, the risk of breaking the wire makes it necessary to limit the tension T to a value considerably below that at which the hot filament would break (e.g. to about one third of the disruptive force).

Because both M and the permissible value of T are proportional to the cross-sectional area of the wire, the maximum attainable resonant frequency depends entirely upon the length. In this respect a short filament, and hence a short electrode system, is desirable.

As a tungsten filament can stand a far higher tension than one of nickel, substantially higher resonant frequencies can be obtained with it. Since, however, the internal damping for mechanical vibrations is greater for nickel than for tungsten, the reverberation time is shorter for a nickel wire.

As an example of what can be achieved to avoid microphony it may be mentioned that the resonance frequency of the filament in the sub-miniature valve DF 64 is as high as 8000 c/s.

Finally it should be pointed out that high demands are imposed, not only upon the filaments themselves, but also upon the springs by which they are stretched, in order to keep the wires under an appropriately reproducible tension.

Summary. The general endeavour to make radio valves of ever smaller dimensions presents a number of problems, some of which are dealt with in this article.

For the smallest types of so-called sub-miniature valves the old pinch-construction, long since abandoned in the manufacture of normal radio valves, was first employed. More recently sub-miniature valves have been successfully made using a pinch-less construction. For the filaments and grids of these valves extremely thin wires are used. The filament is made of tungsten instead of nickel, which results in a reduction in filament current. By making the electrode system short and by using high-quality springs for stretching the filament, the resonant frequency of the filament can be raised, which gives a decrease in valve microphony.

THIN TUNGSTEN WIRE FOR SMALL RADIO VALVES

by L. SCHULTINK and P. G. van ZANTEN.

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For the manufacture of miniature and sub-miniature valves extremely thin wires of tungsten and other metals are required, as discussed in the preceding article. The article below gives some particulars regarding the manufacture of such thin wire and deals with a number of requirements it has to satisfy.

The general aim to reduce the dimensions and the power consumption of radio valves has led to the employment of extremely thin metal wire in the construction of filaments, grids and certain other components. Filaments for sub-miniature and miniature valves, of the directly-heated as well as the indirectly-heated type, are made of *tungsten wire* with a thickness of 50 down to 6 μ — wire of the same material as used for the filaments of incandescent lamps. Certain grids, particularly the "frame grids" used in some valves for professional application [1]), are also wound of tungsten wire. Furthermore, tungsten wire is used for some of the smaller components of radio valves, such as hooks and tiny springs for stretching the filaments.

An impression of the extreme thickness of such wire is given in *fig. 1* in which a 15 μ filament wire is compared with a beard hair, and in *fig. 2* in which a grid and a filament wire of a sub-miniature valve are shown in 8-fold magnification. One handful of tungsten ore is sufficient to make a length of about 350 km of 10 μ wire. Such a length, moreover, satisfies over its entire length the very stringent demands made upon it for the manufacture of radio valves.

Molybdenum wire with a thickness varying between 200 and 25 μ is used for the grids of most miniature and sub-miniature valves. This material is further used as a core or mandrel upon which coiled filaments are wound. At the end of the process the core is removed by dissolving it in a mixture of nitric acid, sulphuric acid and water.

In this article we shall describe the method by which very thin metal wire is manufactured. We shall mainly concern ourselves with tungsten wire, since this is made in the smallest diameter, whilst the process requires the highest degree of accuracy. Molybdenum wire, however, can be manufactured by a nearly identical process.

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[1]) See K. Rodenhuis, H. Santing and H. J. M. van Tol, The life and reliability of valves, Philips tech. Rev. 18, 193-204, 1956/57.

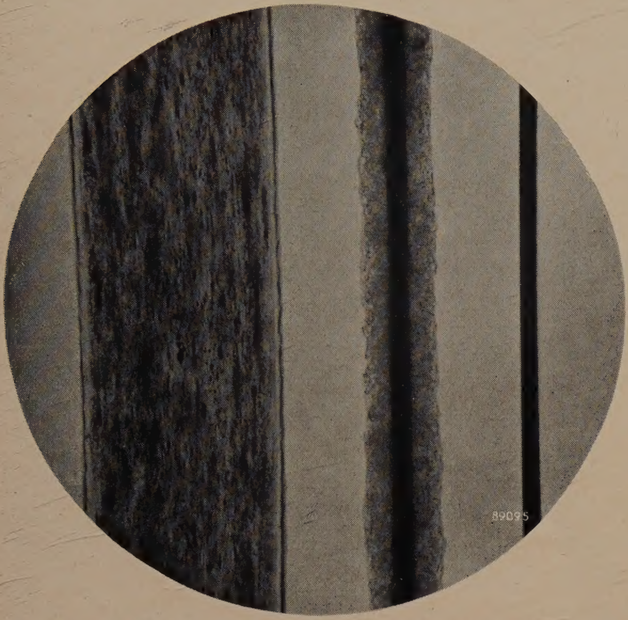

Fig. 1. Tungsten wire of about 15 μ thickness (right) compared with a beard hair (left). In the centre a cross-section of the directly-heated cathode of a sub-miniature valve (tungsten wire, coated with an emitting layer). Magnification approx. 150 ×. This photograph, and that of fig. 2, were made in the laboratory of Mullard Radio Valve Co., Mitcham, England.

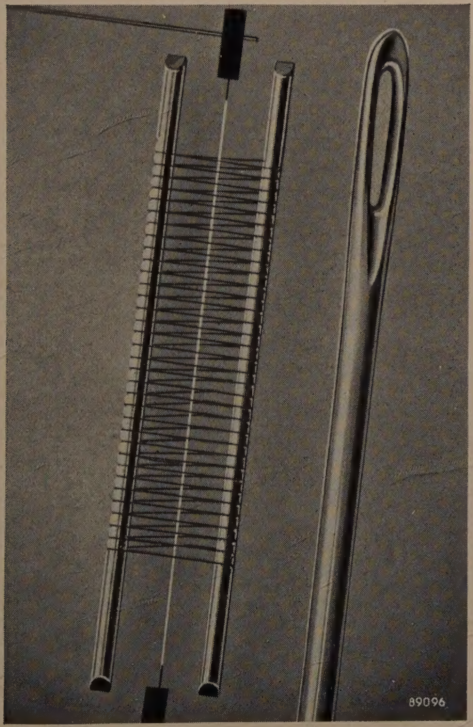

Fig. 2. 8-fold enlargement of a grid and a filament of a sub-miniature valve. The grid is wound of 25 μ molybdenum wire; the filament is a tungsten wire of 11 μ diameter. The sewing needle gives an impression of the actual size.

Material and dimensions of filament wire

The manufacture of filaments for radio valves was initially based on the experience gained in making incandescent lamps. When, between 1930 and 1940, the coiled-coil filament ²) was introduced and generally adopted, the demands made on the material (tungsten) were to be necessarily far higher than those made on the earlier used single-coil wires.

A coiled-coil filament, when heated between two supports, is permitted only the slightest degree of sagging in view of the far greater risk of short-circuiting between the very close windings. After a thorough investigation into the changes in crystal structure occurring in the filament when the lamp is burning, coiled-coil filaments were successfully made whose sagging was sufficiently small to preclude short-circuiting between the windings. The radio-valve industry was able to profit directly from these results and from the experience of the lamp industry. It was of course additionally necessary, for radio valves, to apply the well-known oxide mixture coating, used as electron-emitting material, to the tungsten filament, the latter acting as the actual heating element.

As the development of the thermionic tube progressed, however, it became increasingly clear that as regards both materials and assembly techniques, the considerations relevant to lamps were not necessarily relevant to valves. The special requirements of valves had to be taken into account. For example, in receiver valves of the directly heated type, tungsten as cathode material was superseded by nickel, the latter providing a better base for the emitting substance.

As mentioned in the preceding article ³), there has been a return to tungsten for certain types of valves, particularly for sub-miniature valves. The main reason for this was that for a further reduction of the filament current ever thinner filaments had to be used, for which tungsten is more suitable than nickel. The extremely low current consumption of the sub-miniature valves is indeed mainly attributable to the possibility of manufacturing such thin tungsten wires.

The use of thin tungsten wire, however, is not restricted to sub-miniature valves alone. For valves requiring a larger filament current, it is advantageous to use a cathode consisting of more then one thin wire in parallel. The slope of a valve of this con-

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²) See W. Geiss, The development of the coiled-coil lamp, Philips tech. Rev. **1**, 97-101, 1936.

³) B. A. Cant, Problems in the construction of small radio valves, Philips tech. Rev. **18**, 217-222, 1956/57 (No. 8).

struction, for a given anode current, is greater than that of a valve passing the same filament current through a thicker, single wire.

If the cathode diameter is small with respect to the anode diameter, the former has virtually no effect on the slope at a given current [4]). It is further found that in a cathode consisting of a number of thin wires in parallel, each of these wires contributes about as much to the slope as the amount that can be obtained with one of these wires separately. Hence, by building up the cathode from a number of thin wires the total slope is increased.

Examples of multi-wire filaments include the output valve DL 96, with a cathode of two parallel tungsten wires of 11 μ diameter; the filament current is 50 mA, whilst the max. emission current is 6 mA. The output valve DL 41 employs a cathode of four parallel tungsten wires, likewise of 11 μ diameter; the filament current of this tube is 100 mA, whilst the max. emission current amounts to 12 mA.

The manufacture of very thin tungsten wires

For wire with a diameter greater than 10 μ the normal drawing process, by means of diamond dies, presents no major difficulties [5]).

Drawing still thinner wire, however, becomes increasingly difficult. In spite of the considerable tensile strength of tungsten, a pull of only 25-30 gm will break a 10 μ wire at room temperature; for a diameter of 7.5 μ the breaking stress is reduced to about 15 gm, and for a diameter of 5μ to about 5 gm. Any mechanical working of such wire presents, of course, enormous difficulties.

For the drawing of this wire, a whole series of dies is required, each with a diameter differing only very slightly from the previous one. It is extremely difficult to drill these very small apertures in the diamonds to the narrow tolerances required. The introduction of "electric drilling" (various electro-sparking techniques) [6]) has admittedly simplified the production of diamond dies with very small apertures, but in spite of the advantages of this process it is still far from simple to meet the requirements specified above.

The most commonly used method of making very thin wire is by drawing it to the smallest diameter at which it can still be handled and then further reducing the diameter by an *etching* process. The etching can be done chemically or electrolytically. In the former case either a gas can be used, e.g. oxygen, water vapour or chlorine, or a molten oxidizing agent, such as a mixture of potassium nitrite and potassium nitrate. An aqueous solution of an oxidizing agent such as a mixture of hydrofluoric and nitric acid or of potassium ferricyanide (red prussiate of potash) and sodium hydroxide can also be employed.

A great drawback of all chemical etching methods is the difficulty of carrying out the process with sufficient uniformity. Much simpler in this respect is the process of *electrolytic etching* [7]), in which the wire is passed through a dilute alkaline solution, whilst an electric potential is applied between the wire and an electrode placed in the liquid. If the wire is connected to the positive terminal of the voltage source, its diameter will diminish. An attractive feature of this process is that it can be readily carried out continuously and at room temperature. Furthermore, the surface of the wire is thoroughly cleaned at the same time, this being essential for good emission of the cathode made of this wire. It is for this last reason that wires thicker than 10 μ, which could be fabricated by drawing alone, are also subjected to a subsequent etching process.

The use of the etching process imposes severe demands upon the thicker wire which is to be so treated. Its diameter should be as uniform as possible, since any deviations from the nominal value will become relatively greater after etching. In view of the low tensile strength of the wire, the whole etching apparatus must be constructed with the utmost care. The bobbin from which the wire is reeled off and the guide pulleys should run with a minimum of friction. *Fig. 3* shows an installation for electrolytic etching. The wire successively passes several containers with the etching fluid.

Properties required in the finished wire

To be suitable for the filaments for radio valves, the wire has to satisfy various specific requirements. Some of these requirements can be conveniently expressed as physical quantities, such as diameter uniformity, weight and resistance per unit length, tensile strength and temperature coefficient of resistance. We shall first deal with these requirements, and then mention a few that are less readily expressed as physical quantities.

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[4]) See e.g. H. Rothe and W. Kleen, Grundlagen und Kennlinien der Elektronenröhren, Akademische Verlagsgesellschaft Becker & Erler Kom.-Ges., Leipzig, 1943, 2nd ed., chapters 20 and 4.

[5]) See e.g. J. D. Fast, The preparation of metals in a compact form by pressing and sintering, Philips tech. Rev. 4, 309-316, 1939.

[6]) C. G. Peters, W. B. Emerson, K. N. Neffen, F. K. Harris and J. L. Cooper, Electrical methods for diamond-die production, Industrial Diamond Review 8, 44, 1948.

[7]) See J. O'M. Bockris and D. F. Parsons, Preparation of thin tungsten fibres and their use in place of quartz, J. sci. Instr. **30**, 340, 1953.

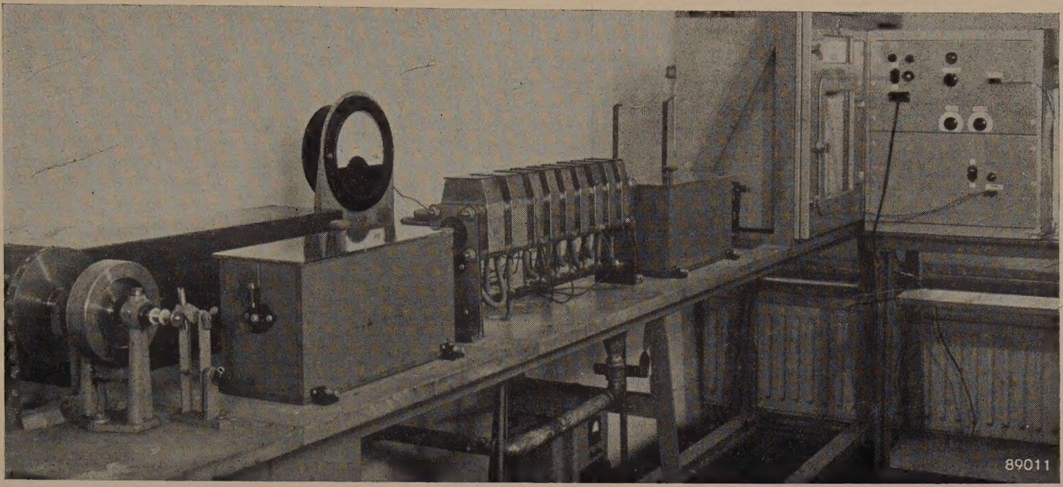

Fig. 3. Installation for the electrolytic etching of very thin metal wire. The wire passes successively through a number of baths of etching fluid.

The *diameter* of the very thin wires considered here can no longer be accurately gauged with the aid of a microscope. In order to test the uniformity of the diameter, moreover, so many measurements must be made that this method is unsuitable for a continuous checking during the manufacturing process. Several continuous methods for gauging the diameter during processing have been described in the literature. Evans, Marriner and Morgan [8]) describe a pneumatic method of gauging. The wire is passed, via two diamond apertures, through a closed chamber into which a gas is fed at a certain constant pressure. If the wire is perfectly uniform in diameter, a constant flow of gas escapes via the apertures in the diamonds. If the diameter is not uniform, on the other hand, the flow of escaping gas will vary, causing fluctuations of the pressure in the compartment. In another gauging method, the wire is passed through a capacitor, variations in diameter thus gauging variations in the capacitance [9]). In either case deviations from the average diameter can be recorded and, by means of special measures, deviations from roundness of the wire can also be detected.

The diameter of the wire may also be evaluated from the *weight per unit length.* In practice this is always done by weighing a length of wire of 200 mm with a sensitive torsion balance. In this way, obviously, only the average diameter of the length of wire can be evaluated.

To measure the *electrical resistance* per unit of length during the manufacturing process, the wire is passed through two mercury contacts, the wire between these contacts forming one arm of a Wheatstone bridge [10]). The sensitivity of these measurements can be increased by reducing the distance between the contacts and the speed of the wire. As an example *fig. 4* shows the result of a measurement of this kind for a tungsten wire of 11 μ, passing at a speed of 15 m/min. between contacts separated by a distance of 20 cm. It is found here that the maximum deviations from the average value amount to ±0.3%. Wires showing variations in the resistance no greater than this are quite suitable for the filaments of radio valves for battery supply.

The *tensile strength* of the wire can be readily determined by measuring the pull under which a wire breaks. Since this is a destructive test, this value can only be established by sample testing, and not

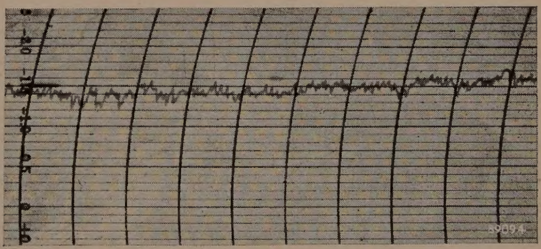

Fig. 4. Recording of the resistance per unit length of a tungsten wire of 11 μ, passing at a speed of 15 m/min through the arm of a bridge circuit. The distance between the contacts was 20 cm. The maximum deviation from the average value is ± 0.3%.

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[8]) J. C. Evans, R. S. Marriner and J. G. Morgan, Continuous pneumatic gauging of fine wire, The Machinist **96**, 679-682, 1952.

[9]) W. W. Loebe and C. Samson, Beobachtungen und Registrierungen von Durchmesserschwankungen dünner Drähte, Z. techn. Phys. **9**, 414-419, 1928.

[10]) See K. Dahl and J. Kern, Ein schreibendes Messgerät zur Messung der Querschnittschwankungen feiner Drähte, E.T.Z. **57**, 1423-1425, 1936.

continuously during the manufacturing process. The same applies to the *temperature coefficient of resistance*. Here, too, samples are taken and tested by measuring the resistance at various temperatures in a Wheatstone bridge.

Among the requirements that are difficult to define or measure as physical quantities are creep, brittleness, roundness, "straightness", surface texture and the presence of splits.

Creep is the slow continuous elongation of the wire when subjected to a constant tensile force. While the creep may be negligible at room temperatures, it can be considerable at the high temperatures at which a valve filament operates. As a result the stress in the filament will be reduced, this increasing the risk of microphony. If the tensile load is large, the wire may even break in the long run. In order to obtain data of practical significance, creep should be measured at high temperature. This measurement requires high-precision equipment and is, moreover, very time-consuming. For these reasons creep measurements as such are as a rule dispensed with, although information of practical value in this connection is often obtained as follows. Samples of the wire are taken and, by means of a small weight or a spring, each wire is subjected to the same tensile stress, which is a multiple of the normal filament stress. The wires are heated to about 800 °C by means of an electric current. If the time that elapses until the various wires break is noted, a curve may be plotted of the number of unbroken wires as a function of the time. The form of this "survival curve" varies according to the process and conditions of manufacture of the wire. Two such curves are shown in *fig. 5*. With the aid of the survival curve of a given batch of wire, the valve designer can decide what voltage and tension may be applied to the wire while keeping the risk of broken filaments in the course of the normal life of the valve below an acceptable limit.

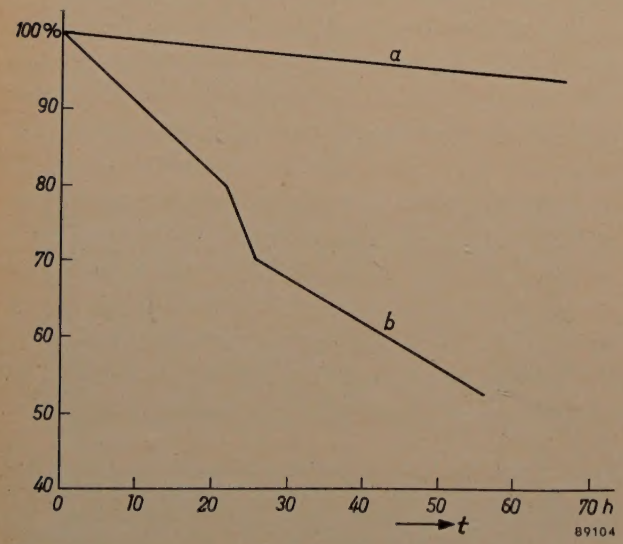


Fig. 5. "Survival curves", indicating the percentage of unbroken wires as a function of the time *t* in hours. The wires were heated in vacuo up to a temperature of 775 °C and subjected to a tensile stress which is a multiple of the normal filament stress. Curve *a* represents a good quality wire; curve *b* a wire of poor quality.

The *brittleness* is generally assessed by bending the wire through a given angle over an edge of a certain radius and counting the number of times this can be repeated before the wire breaks.

For judging the *roundness*, it is possible, but rather difficult to detect slight discrepancies in the circular shape of the cross-section of the final product. A preventive check on the aperture of the last die through which the wire is drawn is a as rule more effective.

As a check on the presence of irregularly distributed internal stresses, a given length of wire is often freely suspended and the extent to which the wire deviates from a straight line is observed. For the sake of brevity this is often referred to as the "*straightness*" of the wire.

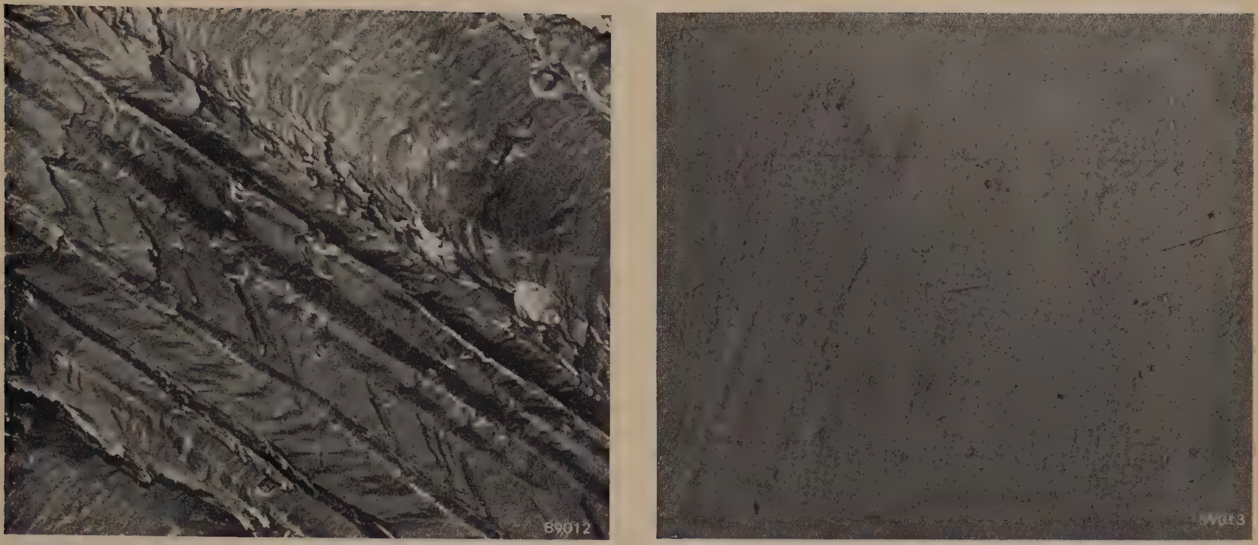
The *surface texture* of the wire can be varied considerably by etching. The surface may vary from glossy to dull. As an example *fig. 6a* and *b* show the surfaces of two wires etched by different processes, at the same magnification.

The detection of local cracks in the wire is extremely difficult. Even with the aid of a microscope it is very difficult to determine whether a wire is cracked or merely shows a deep groove. The issue may be decided by examining a lateral cross-section. As a rule cracks occur when the wire is also in other respects in a generally poor condition.

Coating the wire with alkaline earth carbonates

For use as cathodes in radio valves the wire has to be coated with the carbonates of barium, strontium and sometimes calcium. There are two methods of coating, viz.:

1. *Continuous immersion* ("drag coating"). The wire is passed several times through a suspension of the alkaline earth carbonates to which is added a certain amount of the nitrate of one or more of the above-mentioned metals. Each time the wire is passed through the suspension, a thin layer adheres the wire, which is subsequently sintered to the surface by heating. The nitrates serve here as an inorganic binder. The layer thickness obtained depends upon the speed of the wire, the viscosity of the suspension and the number of times the process is repeated.



a *b*

Fig. 6. The etching process has a profound influence on the surface texture of the wire. The figures show a roughly etched wire (*a*) and a smoothly etched wire (*b*). Magnification 16 000 ×.

2. *Electrophoresis* [11]). The wire is passed through a bath containing a suspension of charged carbonate particles. Under the influence of a voltage of some tens of volts, applied between the wire and an anode in the suspension, the carbonate particles migrate towards the wire, to which they adhere. Appropriate selection of voltage and passing speed of the wire makes it possible to obtain the desired layer thickness in one operation. After drying, an additional coating of a binder is deposited by passing the wire through a solution of this binder.

Decomposition of the carbonates

When the radio valve is being exhausted the wire must be heated in order to convert the carbonate into oxides. At the same time any organic binder present is carbonized and burnt ($CO_2 + C \rightarrow 2\,CO$).

When tungsten is heated with barium carbonate or barium oxide, certain reactions occur with the metallic tungsten; these have been investigated in the Philips Laboratory of Irvington, U.S.A. [12]).

At a temperature of approx. 600 °C, the reaction

$$3\,BaCO_3 + W \rightleftarrows Ba_3WO_6 + 3\,CO$$

is initiated. Since the formation of the semi-conducting barium tungstate is undesirable, this reaction should be avoided. If the temperature is quickly raised to 800-900°, the barium carbonate decomposes according to:

$$BaCO_3 \rightleftarrows BaO + CO_2.$$

If, however, the temperature is raised above 1000 °C, the barium oxide is reduced by the tungsten with the formation of barium tungstate as well as free barium, according to:

$$6\,BaO + W \rightleftarrows Ba_3WO_6 + 3\,Ba.$$

In this way the free barium required for the proper functioning of an oxide cathode is obtained. In view of the fact that only a small quantity of free barium is required, whilst at the same time the formation of the semi-conducting barium tungstate is undesirable [13]), heating at high temperature should take place for a short period only.

The last reaction probably also occurs, if only on a very small scale, during the normal functioning of a radio valve; the free barium lost through evaporation or combination with residual gas is thus made up for.

On normal indirectly-heated oxide-coated cathodes, a carbonate layer with a thickness of 75 μ is usually deposited. For a directly-heated cathode with a diameter of only 8 or 11 μ such a layer is obviously far too thick. The usual layer thickness on a tungsten wire of 11 μ is 20 μ, and even here the ratio of the diameter of the coated wire to that of the tungsten core is so great that the temperature of the core differs a great deal from that at the surface. It is owing to this temperature difference, however, that thin cathodes with a tungsten base can retain a better activity than thicker cathodes. As tungsten is a rather poor reducing agent for the alkaline earth oxides (as compared with silicon, magnesium or aluminium, which are alloyed in normal cathode nickel), a high temperature of the core is required to ensure a permanent supply of free barium. The temperature at the surface, however, determines the rate at which the barium disappears through evaporation and combination with residual gas, and here a not-too-high temperature is favourable.

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[11]) See S. A. Troelstra, Applying coatings by electrophoresis, Philips tech. Rev. **12**, 293-303, 1950/51; H. C. Hamaker, A general theory of lyophobic colloids, Rec. Trav. chim. Pays-Bas **55**, 1015-1026, 1936 and **56**, 3-25, 1937; H. C. Hamaker, A system of colloid phenomena, Rec. Trav. chim. Pays-Bas **56**, 727-747, 1937; L. E. Grey and R. O. Jenkins, Electrophoresis in the valve industry, Electronic Engineering **26**, 402-405, 1954.

[12]) R. C. Hughes, P. P. Coppola and H. T. Evans, Chemical reactions in barium oxide and tungsten emitters, J. appl. Phys. **23**, 635-641, 1952.

[13]) Similar semi-conducting products, formed during the reduction of barium oxide have recently been the subject of further research; see e.g. J. F. Waymouth, Deterioration of oxide-coated cathodes under low-duty-factor operation, J. appl. Phys. **22**, 80-86, 1951 and L. S. Nergaard and R. M. Matheson, Studies of the interface layer in oxide cathodes, R. C. A. Review **15**, 335-361, 1954.

It is interesting to note that for a given filament current the temperature of the core depends very little on the thickness of the coating, unlike the temperature at the surface which is strongly correlated with the thickness.

Results of life tests

The emission current that can be supplied by an oxide-coated cathode with a core of thin tungsten wire, is difficult to predict with any accuracy, since this depends greatly on the purity of the materials involved. The quantity of oxide on a length of wire of 2 cm having a diameter of 11 μ amounts to approx. 30 μg. If we assume that 0.01% of this consists of free barium [14]), then it follows that 0.003 μg of active material is available on the cathode. Clearly, the production of valves in which the quantity of free barium remains roughly constant during the entire working life, whilst at the same time the formation of undesirable tungstates is kept within reasonable limits calls for the strictest precautions and the highest precision. A further requirement is that the filament voltage should be permitted to vary within the wide limits between which the terminal voltages of dry batteries are apt to vary. Nevertheless it is found possible to obtain satisfactory results in practice. As an example, *fig. 7* shows some results of life test on the miniature valve DL 96. The per cent change in slope, measured with varying filament voltages, as plotted in this diagram, appears to lie well within acceptable limits after several hundreds of burning hours.

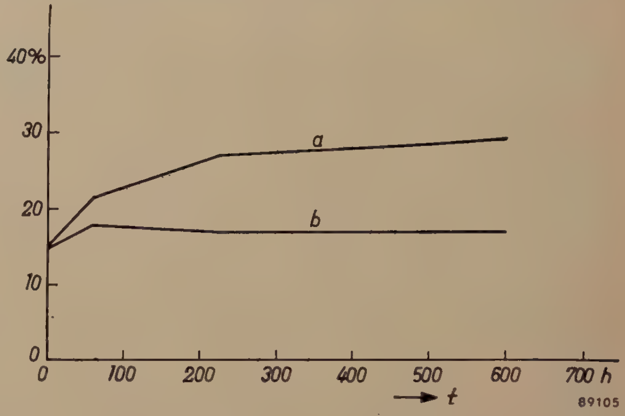

Fig. 7. Results of life tests on a number of DL 96 valves. Curve *a* was measured on valves under a filament voltage of 1.5 V, having a cathode-emission current of 5.1 mA during the life test. Plotted along the ordinate is the per cent change in slope when the filament voltage is varied from 1.4 to 1.0 V (at an anode current of 5 mA). Curve *b* relates to valves under a filament voltage of 1.1 V, having an emission current of 4 mA throughout the life test. The time *t*, along the abscissa, is plotted in hours.

Summary. Filaments for electronic valves were initially made of tungsten. Later this material was superseded by nickel, but in the sub-miniature valves developed in the last two decades tungsten has been reinstated as filament material. The reason for this is the greater tensile strength of this material, thanks to which the filament can be made thinner, whilst a far smaller filament current will suffice. The most commonly employed method for making very thin wire is the electrolytic etching of thicker wire. The principal requirements for the wire to be suitable as filament material are high tensile strength and low creep. The wire is coated with a layer of alkaline earth carbonates. The principal method of coating is by means of electrophoresis. During pumping of the valve, prior to sealing, the carbonates are decomposed into oxides by heating the filament. For very thin filament wires the ratio of the diameter of the coated wire to that of the bare core is fairly high. Owing to the difference in temperature thus caused between core and surface, such cathodes will retain their activity far longer.

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[14]) R. O. Jenkins and R. H. C. Newton, Free barium in and evaporated from oxide cathodes, Nature **163**, 572, 1949.

NUCLEAR X-RAY SOURCES

by S. FINE *) and C. F. HENDEE *).

539.167.3:537.531:621.387.4

With the rapidly expanding availability of artificially produced radioisotopes (radioactive nuclides) it has become possible to use many of these as radiation sources for routine work. Nuclides directly emitting soft X-rays have been put to such use in recent years. The authors have made a survey of X-ray emitting nuclides and have prepared a number of X-ray sources of this type ("nuclear X-ray sources") which have proved very valuable in work on and with X-ray counter tubes.

Radioactive substances, either natural or artificial, have been employed for a long time as sources of α- and β-particles and of high energy photons (γ-rays). A classical example is natural radioactive polonium, specimens of which are often used for demonstrating the effects of α-radiation or for checking apparatus sensitive to it. A younger member of this family is the artificial radioisotope of cobalt (Co 60) emitting 1.17 MeV and 1.33 MeV γ-rays. Radiation of similar energy, which is used, inter alia, for industrial radiography and for therapeutic irradiation, may also be obtained from X-ray tubes run at voltages up to 2 MeV, or from betatrons or linear accelerators ¹). Nevertheless the radioactive γ-ray source has proved a very valuable extension of the array of high-energy X-ray machines.

In addition to the energetic particles and high energy photons, resulting from the decay of radioactive nuclei, photons of lower energy, e.g. less than 100 keV (soft X-rays), are in some cases emitted. Because the investigation of nuclear processes usually involves an interpretation of high energy events, there has been little emphasis on the low energy phenomena. In fact the latter ofter appear only as perturbations or corrections in nuclear theory (background or noise).

Only in recent years has it been realized that the emission of low energy X-rays by some radioactive nuclides can be put to good use ²), just as useful applications have been found for γ-ray emitters such as cobalt 60. Interest in this possibility was prompted by the development of X-ray quantum counting techniques. For checking and calibrating proportional and scintillation counters developed for X-ray detection ³), very stable monochromatic X-ray sources were required. X-ray emitting nuclides ("nuclear X-ray sources"), while lacking the easy controllability and the very large radiation output of modern X-ray generating equipment, usually greatly surpass the latter in stability and therefore promised to be useful in work with X-ray counters.

Unfortunately, nuclear X-ray sources have not yet become a commercially available product, probably owing to the tendency among physicists to be more preoccupied with high energy phenomena. It seemed desirable, therefore, to survey the presently known artificially produced radioisotopes from the viewpoint of X-ray production. This survey is offered in this article, together with a discussion of the underlying phenomena in the nuclear X-ray source and a description of some sources which have been developed and are currently used in the Philips Laboratories at Irvington ⁴).

Mechanisms of X-ray emission by radioactive nuclides

There are two decay processes of radioactive nuclei which lead directly to the emission of X-rays ⁵):

1) Internal conversion of emitted gamma rays.
2) Capture of orbital electrons.

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*) Philips Laboratories, Irvington-on-Hudson, N.Y., U.S.A.

¹) See e.g. I. Kaplan, Nuclear physics, Addison-Wesley, Cambridge (Mass.), 1955. See also Philips techn. Rev. **4**, 153-161, 1939; **15**, 1-26, 1953/54; **17**, 31-33, 1955/56.

²) G. M. Insch, Phil. Mag. 7, **41**, 857-862, 1950.
P. Rothwell and D. West, Proc. Phys. Soc. **A63**, 541-543, 1950.
W. V. Mayneord, Brit. J. Radiology **25**, 517-525, 1952.

³) See e.g. W. Parrish and T. R. Kohler, Rev. sci. Instr. **27**, 795-808, 1956; also P. H. Dowling, C. F. Hendee, T. R. Kohler and W. Parrish, Counter tubes for X-ray analysis, Philips tech. Rev., to appear shortly.

⁴) Part of the material of this article was presented by S. Fine and C. F. Hendee at the Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy, Feb. 1956.

⁵) X-rays can also be produced indirectly, by α, β or γ-rays emitted from a radionuclide and impinging on a suitable target material. These methods have been known and applied for a long time. I. Curie and F. Joliot discussed this possibility with reference to α-rays (J. Phys. Rad. **2**, 20-28, 1931); for β-ray excitation, see L. Reiffel, Nucleonics **13**, No. 3, March 1955, pp. 22-24. Although these methods certainly should not be overlooked, we shall not consider them in this article.

Both these mechanisms can be readily described when it is remembered how the characteristic X-ray emission of an atom, say the K-lines, is produced: an electron is removed from an orbit in the K-shell, and the vacancy so produced is filled by an electron from one of the outer shells, each of the possible transitions being accompanied by the emission of the energy difference as an X-ray quantum of corresponding wavelength. In the target of an X-ray tube, the removal of a K-electron (or of an L-electron for the emission of L-lines, etc.) is effected by electron impact. This is different from the above-mentioned mechanisms occurring in radioactive nuclides.

In the first mechanism, a nucleus being in an excited state decays to its normal state and emits a gamma quantum; the latter has a finite probability of ejecting an orbital electron of the atom. The efficiency of this process (coefficient of "internal conversion", i.e. average number of electrons ejected per gamma quantum) increases with the atomic number Z and with the lifetime of the excited state, and rather rapidly with decreasing gamma quantum energy. The efficiency will be high and may even approach unity for nuclei in a *metastable* ("*isomeric*") excited state, since such states are long-lived and generally have low excitation energies (small gamma quanta). Nuclei of this type can therefore be effective X-ray sources (the effectiveness, however, depending also on other factors, see hereafter).

In the second mechanism, the orbital electron is not ejected but swallowed (captured) by the unstable nucleus itself. In this process the nucleus of atomic number Z loses one positive charge, and the X-ray photons subsequently emitted by the filling of the orbital vacancy are characteristic of the new atom, with atomic number $Z-1$. This should be contrasted with the first mechanism, in which no change of nuclear charge takes place and the characteristic X-ray spectrum of the atom of atomic number Z is emitted.

It should be noted that in both cases a pure characteristic X-ray spectrum is emitted, *not* containing a Bremsstrahlung continuum which is unavoidable in X-ray tubes. This is an important feature for X-ray sources whose emissions are used as wavelength standards, e.g. in high resolution spectroscopy.

The K-electrons are most frequently ejected or captured by the nuclear processes described above, because of their close proximity to the nucleus. However, there is a finite probability for the ejection or capture of L-, M- etc. electrons.

List of X-ray emitting nuclides

About 100 radioactive nuclides decaying by the above processes and producing X-rays are known, with half-lives varying from hours to thousands of years and X-ray wavelengths varying from 2.5 to 0.15 Å (energies 5 to 80 keV). *Table I* is a partial listing of these nuclides together with some of their important characteristics. The information was assembled from literature and official publications on isotopes available from atomic piles or cyclotrons [6]). In assembling the list, an attempt was made to select nuclides with K emissions in a somewhat continuous series up to 75 keV. Nuclides with a half-life of less than ten days are not listed, since their radiation intensity will decrease too rapidly for most practical purposes.

The nuclides are produced in nuclear reactions caused by the bombardment of target substances. The reactions are listed in the third column of the table. In all cases the target materials are naturally stable isotopes, whose abundance is also given in the table; the increased abundance indicated in the next column refers to enriched specimens obtainable from the Oak Ridge National Laboratories, U.S.A. The mechanism of X-ray emission is indicated under the heading "Decay mode". In the next column the table gives the element whose characteristic K-lines are emitted, and the energy of $K\alpha_1$ [7]). In most cases other emissions, such as γ-radiation, conversion electrons (e^-) or electrons from the nucleus (β^-) accompany X-ray emission (last column). These need not be an interfering factor in many applications. If necessary, the electrons may be eliminated by metal foil or plastic film filters, while the γ-rays may be minimized by electronic discrimination [3]).

It is to be noted that Table I includes nuclides that emit the characteristic radiations of the X-ray tube target materials commonly used for X-ray diffraction and spectrochemical analysis, namely Cr, Fe, Co, Cu, Mo, Ag and W.

In some cases the new nucleus resulting from an electron capture process is in a metastable excited

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[6]) J. M. Hollander J. Perlman and G. T. Seaborg, Table of isotopes, Rev. mod. Phys. **25**, 469-651, 1953. A. H. W. Aten and J. Halberstadt, The production of radioisotopes, Philips tech. Rev. **16**, 1-12, 1954/55. This article also gives a brief exposition of a number of nuclear reactions and of chemical methods used in the separation of the isotopes. J. R. Bradford, Chart of the isotopes, publ. Harshaw Scientific. G. Friedländer and M. Perlman, Chart of the nuclides (revised by J. R. Stehn), publ. General Electric, U.S.A.

[7]) S. Fine and C. F. Hendee, X-ray critical-absorption and emission energies in keV, Nucleonics **13**, No. 3, March 1955, pp. 36-37.

Table I. Partial list of X-ray emitting radioactive nuclides, with their half-life, nuclear reactions by which they are produced, decay mode, and emitted radiation. Under decay mode, EC stands for electron capture process, IT for internal conversion or transition and m for metastable nucleus; competing processes by which some nuclei can decay (β^+-emission) are also indicated; in some cases decay involves successive processes.

Radioactive nuclide		Target			Radiation		
Symbol and mass number	Half-life	Reaction	Natural abundance %	Increased abundance %	Decay mode	X-ray $K\alpha_1$ (keV)	Other
Be^{7}	53 d	$\mathrm{Li}^{7}(\mathrm{d,2n})\mathrm{Be}^{7}$	92.6	—	EC	Li 0.052	γ
Ca^{41}	1.1×10^{5} y	$\mathrm{Ca}^{40}(\mathrm{n},\gamma)\mathrm{Ca}^{41}$	96.97	—	EC	K 3.31	—
V^{49}	1 y	$\mathrm{Ti}^{48}(\mathrm{d,n})\mathrm{V}^{49}$	73.45	99.2	EC	Ti 4.51	—
Cr^{51}	27 d	$\mathrm{Cr}^{50}(\mathrm{n},\gamma)\mathrm{Cr}^{51}$	4.31	88.3	EC	V 4.95	γ
Mn^{54}	300 d	$\mathrm{Cr}^{53}(\mathrm{d,n})\mathrm{Mn}^{54}$ $\mathrm{Fe}^{56}(\mathrm{d},\alpha)\mathrm{Mn}^{54}$	9.55 91.68	92.1 99.9	EC	Cr 5.41	γ
Fe^{55}	2.94 y	$\mathrm{Fe}^{54}(\mathrm{n},\gamma)\mathrm{Fe}^{55}$	5.84	93.3	EC	Mn 5.90	—
Co^{57}	270 d	$\mathrm{Fe}^{56}(\mathrm{d,n})\mathrm{Co}^{57}$	91.68	99.9	$\beta^+ \rightarrow \mathrm{IT}(\mathrm{Fe}^{57\mathrm{m}})$	Fe 6.40	γ, e^-
Co^{58}	72 d	$\mathrm{Fe}^{57}(\mathrm{d,n})\mathrm{Co}^{58}$	2.17	87.3	EC, β^+	Fe 6.40	γ
Ni^{59}	7.5×10^{5} y	$\mathrm{Ni}^{58}(\mathrm{n},\gamma)\mathrm{Ni}^{59}$	67.76	99.3	EC	Co 6.93	—
Zn^{65}	250 d	$\mathrm{Zn}^{64}(\mathrm{n},\gamma)\mathrm{Zn}^{65}$ $\mathrm{Cu}^{65}(\mathrm{d,2n})\mathrm{Zn}^{65}$	48.89 30.9	93.4 98.2	EC, β^+	Cu 8.05	γ
Ge^{71}	11.4 d	$\mathrm{Ge}^{70}(\mathrm{n},\gamma)\mathrm{Ge}^{71}$	20.55	88.1	EC	Ga 9.25	—
As^{73}	76 d	$\mathrm{Ge}^{72}(\mathrm{d,n})\mathrm{As}^{73}$	27.37	89.2	EC	Ge 9.89	γ, e^-
Se^{75}	127 d	$\mathrm{Se}^{74}(\mathrm{n},\gamma)\mathrm{Se}^{75}$	0.87	33.1	EC	As 10.54	γ, e^-
Y^{88}	105 d	$\mathrm{Sr}^{88}(\mathrm{d,2n})\mathrm{Y}^{88}$	82.56	99.7	EC, β^+	Sr 14.16	γ
Mo^{93}	>2 y	$\mathrm{Mo}^{92}(\mathrm{n},\gamma)\mathrm{Mo}^{93}$	15.86	95.5	EC	Nb 16.61	—
Tc^{95}	60 d	$\mathrm{Mo}^{94}(\mathrm{d,n})\mathrm{Tc}^{95\mathrm{m}}$	9.12	79.1	EC	Mo 17.48	γ
Pd^{103}	17 d	$\mathrm{Rh}^{103}(\mathrm{d,2n})\mathrm{Pd}^{103}$ $\mathrm{Pd}^{102}(\mathrm{n},\gamma)\mathrm{Pd}^{103}$	100.00 0.8	— —	$\mathrm{EC} \rightarrow \mathrm{IT}(\mathrm{Rh}^{103\mathrm{m}})$	Rh 20.21	γ, e^-
Cd^{109}	330 d	$\mathrm{Cd}^{108}(\mathrm{n},\gamma)\mathrm{Cd}^{109}$ $\mathrm{Ag}^{109}(\mathrm{d,2n})\mathrm{Cd}^{109}$	0.89 48.65	24.8 99.6	$\mathrm{EC} \rightarrow \mathrm{IT}(\mathrm{Ag}^{109\mathrm{m}})$	Ag 22.16	γ, e^-
Sn^{113}	112 d	$\mathrm{Sn}^{112}(\mathrm{n},\gamma)\mathrm{Sn}^{113}$	0.95	72.5	EC	In 24.21	γ
In^{114}	49 d	$\mathrm{In}^{113}(\mathrm{n},\gamma)\mathrm{In}^{114\mathrm{m}}$ $\mathrm{Cd}^{114}(\mathrm{d,2n})\mathrm{In}^{114\mathrm{m}}$	4.23 28.86	65.4 94.2	IT	In 24.21	γ, β^-, e^-
Ba^{133}	9.5 y	$\mathrm{Cs}^{133}(\mathrm{d,2n})\mathrm{Ba}^{133\mathrm{m}}$	100.00	—	$\mathrm{IT} \rightarrow \mathrm{EC}(\mathrm{Ba}^{133})$	Cs 30.97	γ, e^-
Cs^{137}	33 y	Fission product			$\beta^- \rightarrow \mathrm{IT}(\mathrm{Ba}^{137\mathrm{m}})$	Ba 32.19	γ, e^-
Sm^{145}	410 d	$\mathrm{Sm}^{144}(\mathrm{n},\gamma)\mathrm{Sm}^{145}$	3.16	—	EC 30y EC (Pm^{145})	Pm 38.65 Nd 37.36	γ, e^-
Gd^{153}	236 d	$\mathrm{Gd}^{152}(\mathrm{n},\gamma)\mathrm{Gd}^{153}$ $\mathrm{Eu}^{153}(\mathrm{d,2n})\mathrm{Gd}^{153}$	0.2 52.23	— —	EC	Eu 41.53	γ, e^-
Dy^{159}	140 d	$\mathrm{Tb}^{159}(\mathrm{d,2n})\mathrm{Dy}^{159}$	100.00	—	EC	Tb 44.47	—
Yb^{169}	33 d	$\mathrm{Tm}^{169}(\mathrm{d,2n})\mathrm{Yb}^{169}$	100.00	—	EC	Tm 50.73	γ, e^-
Tm^{170}	127 d	$\mathrm{Tm}^{169}(\mathrm{n},\gamma)\mathrm{Tm}^{170}$	100.00	—	$\beta^- \rightarrow \mathrm{IT}(\mathrm{Yb}^{170\mathrm{m}})$	Yb 52.36	β^-, γ, e^-
Hf^{175}	70 d	$\mathrm{Lu}^{175}(\mathrm{d,2n})\mathrm{Hf}^{175}$	97.40	—	EC	Lu 54.06	γ, e^-
W^{181}	140 d	$\mathrm{Ta}^{181}(\mathrm{d,2n})\mathrm{W}^{181}$	100.00	—	EC	Ta 57.52	γ, e^-
Re^{183}	120 d	$\mathrm{Ta}^{181}(\alpha,\mathrm{2n})\mathrm{Re}^{183}$	100.00	—	EC	W 59.31	γ, e^-
Re^{184}	50 d	$\mathrm{Re}^{185}(\mathrm{n,2n})\mathrm{Re}^{184}$	37.07	85.4	EC	W 59.31	γ, e^-
Os^{185}	97 d	$\mathrm{Re}^{185}(\mathrm{d,2n})\mathrm{Os}^{185}$	37.07	85.4	EC	Re 61.13	γ, e^-
Au^{195}	185 d	$\mathrm{Pt}^{194}(\mathrm{d,n})\mathrm{Au}^{195}$	32.8	—	EC	Pt 66.82	γ, e^-
Tl^{202}	11.5 d	$\mathrm{Hg}^{201}(\mathrm{d,n})\mathrm{Tl}^{202}$	13.22	71.8	EC	Hg 70.82	γ, e^-
Tl^{204}	2.7 y	$\mathrm{Tl}^{203}(\mathrm{n},\gamma)\mathrm{Tl}^{204}$	29.50	96.0	EC, β^-	Hg 70.82	β^-
Bi^{207}	50 y	$\mathrm{Pb}^{206}(\mathrm{d,n})\mathrm{Bi}^{207}$	23.6	81.0	EC	Pb 74.96	γ, e^-

state and decays to the normal state with internal conversion. Thus, two X-ray photons, characteristic of the same element ($Z-1$), may be successively emitted. Cd^{109} and Pd^{103} are examples of these "double emitters".

Photon flux density of nuclear X-ray sources

The usefulness of a nuclear X-ray source generally will depend on the photon flux density of the radiation obtained, i.e. the number of X-ray photons emitted per sec and per cm². Given a sample of infinite thickness (see below) of a pure nuclide, the flux density is a characteristic of the material. For iron Fe^{55} e.g. it is 25×10^{10} photons /sec cm².

Some factors governing this characteristic may be indicated. The first factor is the specific activity, i.e. the number of disintegrations per second occurring in one gram of the pure nuclide. It is measured in curie/gram (c/g), one curie corresponding to 3.7×10^{10} disintegrations/sec. For isotopically pure Fe^{55}, the specific activity would be 2.2×10^3 c/g. Other factors are: the branching ratio, i.e. the fraction of the total number of disintegrations due to any one of the X-ray producing mechanisms described; the internal conversion coefficient mentioned above, when internal conversion is the X-ray producing mechanism; the fluorescence yield, i.e. the fraction of the created K (or L, ...) vacancies resulting in the emission of K (or L, ...) photons; and the absorption of the X-ray producing element for the characteristic radiation emitted ("self-absorption" coefficient μ_K or μ_L, ...). Owing to the latter factor an increase in thickness of a nuclide layer does not provide a proportional increase in radiated flux density but a saturation is approached so that a source of a certain minimum thickness will have practically the same flux density as the infinite source.

The preparation of a nuclear X-ray source in usable from starts from a powdered, solid or dissolved specimen material, supplied by an atomic pile or a cyclotron [6]). This material, in general, contains the desired nuclide not in a pure form but mixed with other isotopes of the same element, which cannot be separated by normal laboratory means. The useful specific activity, i.e. the activity per gram of the *element*, is usually greatly lowered by these admixtures. Moreover, the other isotopes may give rise to contamination of the X-rays by undesired radiations. In order to minimize these adverse effects, the target material in the pile or cyclotron should contain the useful nuclide — from which the radionuclide in question is generated — in the highest possible concentration (target of increased abundance, cf. Table I). Obviously a high flux of the bombarding particles is also favourable for attaining high specific activities, since it will increase the theoretically attainable level of specific activity, at which equilibrium exists between the formation of new nuclei and the disintegration of nuclei already formed. The latter advantage is particularly important when the desired nuclide is contaminated by radioactive isotopes having a longer half-life: in that case, it may be desirable to keep the actual specific activity well below the theoretically attainable level (by reducing the irradiation period of the target) in order not to get an X-ray source unduly contaminated by unwanted radiations.

The specific activities normally commercially available are given in *Table II* for a number of nuclides important as X-ray sources. Higher specific activities may be obtained in many cases at higher cost and longer delay in delivery. The last column of the table gives the calculated X-ray photon flux densities of infinitely thick samples of these specimens.

Table II. Specific activity of normally available specimens of X-ray emitting nuclides, and X-ray photon flux density of infinite thickness samples.

Nuclide	Specific activity (millicurie per gram of element)	Photon flux density (10^7 photons per sec.cm²)
Cr^{51}	400	2.85
Fe^{55}	1500	16.7
Ni^{59}	0.005	0.000087
Zn^{65}	5000	122
Ge^{71}	700	20.5
Se^{75}	100	3.25
Sn^{113}	1.6	0.283
In^{114}	720	129
Tm^{170}	10000	330
Tl^{204}	300	6.1

For an appreciation of these values consider the case of Fe^{55}, on which most of the nuclear X-ray work in this laboratory was done. The Fe^{55}-sources are usually used in a configuration shown in *fig. 1.*

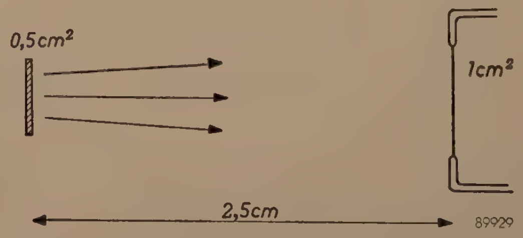

Fig. 1. Usual configuration of nuclear X-ray source (left) and counter tube under test (right).

The X-rays are emitted from a source of 0.5 cm² area and enter the window of the detector (counter tube) to be checked or calibrated. The window area in most cases was 1 cm², the distance 2.5 cm. Under these conditions, the counter window encompasses about 1% of the radiation emitted by the source in all directions. The counting rate (at 100% counting efficiency of the detector) to be expected from a 0.5 cm² source of infinite thickness of Fe^{55} having a flux density of 16.7×10^7 photons/sec.cm² would therefore be 8.4×10^5 counts/sec. With a "self-absorption" coefficient $\mu \approx 700$ cm^{-1} of the source, i.e. the absorption coefficient of iron for the emitted MnKα radiation (2.1 Å, 5.90 keV), it is calculated that even a source 0.03 mm (0.0012″) thick would give 90% of the maximum rate. Several of the Fe^{55} sources prepared in this laboratory from a batch of Fe^{55} of the above-mentioned specific activity approached a rate of 8×10^4 counts/sec, i.e. 10% of the maximum rate (the corresponding thickness of the layer is calculated to be about 0.002 mm or 0.0001″). This counting rate is amply sufficient for practical purposes, since larger counting rates would in any case have to be attenuated in order not to choke the counting systems at present available [3]).

For the calculation of the absorption effect use is made of Dixon's calculations for large gamma-ray sources [8]). The configuration of fig. 1 approximately meets the conditions that all detected photons traverse the source in a direction perpendicular to its surface and that the source has equal thickness in all parts of the beam cross-section. Under these conditions and with the assumptions of a homogeneous source, no scatter in the source and no absorption in the source holder window, the self-absorption in a source of thickness D is expressed by the equation [9]):

$$\frac{I}{I_0} = \frac{1}{\mu D}\left(1 - \mathrm{e}^{-\mu D}\right).$$

I and I_0 are the flux densities with and without self-absorption respectively. I_0 evidently will be proportional to the thickness of the source:

$$I_0 = G\times D$$

and hence

$$I = \frac{G}{\mu}\left(1 - \mathrm{e}^{-\mu D}\right).$$

For $D \rightarrow \infty$, the flux density approaches the value G/μ, which in fact is the value listed in Table II. From the last equation the flux density of a source of any thickness can be calculated.

An obvious question is whether the flux density of the Fe^{55} source or other nuclear X-ray sources would render them possible substitutes for X-ray tubes in various applications, such as diffractometry and radiography. In diffractometry, however, the *utilization* of the X-rays emitted by the source is enormously poorer than in the configuration of fig. 1, so that much larger flux densities of the source are needed to get adequate counting rates in the diffraction lines. To illustrate this point, it should be mentioned that a normal diffraction X-ray tube with a loading of only 0.1 mW would emit approximately the same total number of K-photons/sec ($\sim 10^7$) as the best practical 0.5 cm^2 Fe^{55} source described here [10]). Since the actual loading of diffraction tubes may amount to 1 kW and their effective source size is e.g. 0.015 cm^2, the Fe^{55} source is evidently inferior by a factor of more than 10^8. In radiography, the advantage of the X-ray tube as a source is even more pronounced since the continuous spectrum which the tube emits and which is useless in diffraction analysis, is fully effective photographically. In this case the Fe^{55} source would be equivalent to an X-ray tube with a specific loading of only appr. 0.5 μW/mm^2. This should be compared to the actual loading applied in normal radiography, which may be 4×10^8 times higher (200 W/mm^2) for a stationary anode and even 10^{10} times higher (8000 W/mm^2) for a rotating anode (short exposures).

Obviously, then, the Fe^{55} source even at its theoretical maximum (i.e. with the radionuclide in a pure, undiluted state) cannot compete with the X-ray tube in flux density. Other radioactive nuclides may have higher theoretical flux density limits; however, because of the fundamental relationship between specific activity S and half-life T of a radioactive element,

$$S = \frac{4.16\times10^{23}}{A\times T}$$

(T being measured in seconds and A being the atomic weight), flux densities comparable to those of X-ray tubes will be attainable only with nuclides far too short-lived for practical purposes.

Preparation of the sources [11])

A number of factors led us to select Fe^{55} as the main nuclide for our experimental X-ray sources. Fe^{55} was found suitable for the envisaged applications not only because of the wavelength of the emitted MnKα radiation but also by virtue of its 3 year half-life and its decay by pure electron capture unaccompanied by processes generating other radiations. It has furthermore been shown in the above that the specific activity of the available Fe^{55} specimens permits the fabrication of sources of sufficient X-ray intensity for work on counter tubes.

The radioactive Fe^{55} is obtained from the suppliers in the form of an FeCl$_3$ solution, from which Fe^{55} may be laid down in some solid, homogeneous form by means of a number of chemical and physical techniques. Three methods were successfully used. (Similar techniques are applicable to most other X-ray emitting nuclides.)

1) The filter paper method. Several drops of the active solution are transferred to a 1 cm^2 piece of filter paper which has been positioned in a previously prepared holder. The assembly is then sealed with 12 μ polyester film, which is 98% transparent to the MnKα radiation and which prevents the FeCl$_3$ solution giving off HCl-vapor. This simple procedure produces a stable source, which, however, is rather weak owing to the diluted state of the radioactive nuclide and the absorption of X-rays by Cl atoms

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[8]) W. R. Dixon, Nucleonics **8**, No. 4, April 1951, pp. 68-72.

[9]) Cf. e.g. D. Taylor, The measurement of radioisotopes, Methuen and Co., London, 1951.

[10]) This calculation and the following ones are due to W. J. Oosterkamp of the Philips Laboratory at Eindhoven. Cf. also: W. J. Oosterkamp, The radiography of the human body with radioactive isotopes, Brit. J. Radiol. **26**, 111, 1953.

[11]) The authors gratefully acknowledge the assistance of W. B. Brown of this laboratory in this phase of the work.

(mass absorption coefficient for 2 Å appr. 300) and by the filter paper.

2) The ammonia method. From a drop of the active $FeCl_3$ solution placed on a small glass or metal plate, $Fe(OH)_3$ is precipitated by means of an ammonia atmosphere. Heating the plate then converts the iron hydroxide into the non-volatile iron oxide which strongly adheres to the base material. No window is necessary and the absorption is substantially lower than in the previous case (the mass absorption coefficient of the oxygen atoms for 2 Å is only about 30). Even higher intensities can be obtained when the oxide is subsequently reduced in an H_2-atmosphere and, for protection, the metallic Fe fused into a platinum backing by heating. This method was developed at Oak Ridge National Laboratory [12]).

3) Electroplating. This method, whereby pure Fe^{55} can be deposited in successive thin layers, results in maximum concentration of the radioactive material and in the highest photon flux densities attained. Conventional procedures for electroplating iron proved not amenable to the microtechniques involved in the preparation of radioactive sources. A procedure was worked out after a suggestion by Platzer and Lewis [13]), the main problem being to avoid etching away of the deposited iron by acid formed in the electrolysis of the $FeCl_3$-solution. *Fig. 2* shows the equipment used. A small amount of the active solution, to which no "carrier" substance is added, is pipetted onto a filter paper placed on a graphite anode. A copper plate forming the cathode, on which the Fe is to be plated, is held on a movable fixture and is lowered into position on the filter paper, while a potential of 3 V is applied to the electrodes. After the deposition process, the whole structure is flooded with a spray of water to was haway the formed acid [14]). The process can be repeated with a fresh $FeCl_3$ portion, and in this way as many as ten successive layers have been plated onto one backing piece, building up a total thickness which produces 10% of the infinite-thickness flux density (see above).

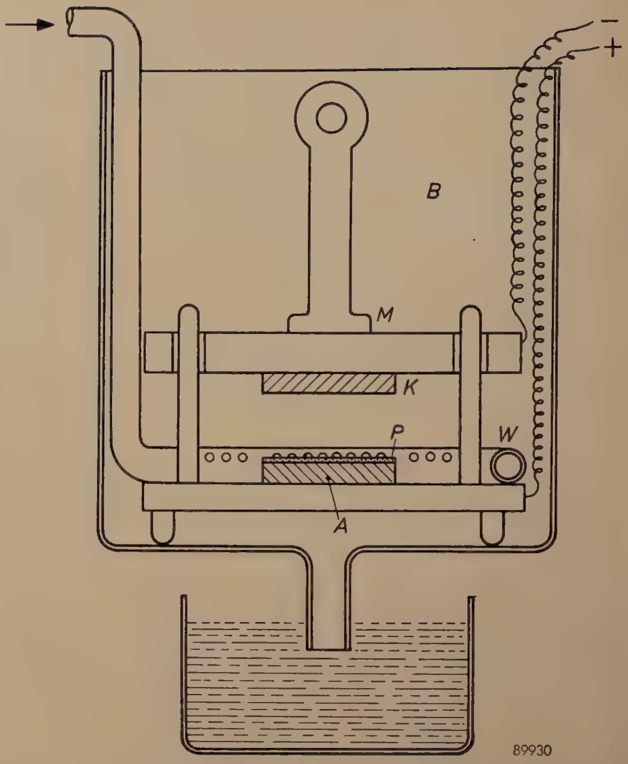

Fig. 2. Equipment for electroplating Fe^{55}. *K* copper plate on which Fe^{55} is to be deposited, held by the movable fixture *M* in glass beaker *B*. *P* filter paper placed on graphite anode *A* and saturated with radioactive $FeCl_3$ solution. A 3V potential is applied between *K* and *A* and the cathode *K* is then lowered onto the filter paper. After the plating process, wash water is sprayed on the electrodes from a perforated ring *W* before the electrodes are separated.

Similar techniques have been evolved to deposit Zn^{65}. This radioactive nuclide is particularly important since it emits CuKα rays (λ = 1.54 Å, energy 8.05 keV). From the tables it is seen that the half-life of this source is 250 days and that the infinite-thickness flux density of the best specimens at present obtainable is 122×10^7 photons/sec cm^2.

The design of the *holder* for the nuclear X-ray source depends on the intended application, since it should provide means for proper positioning in the

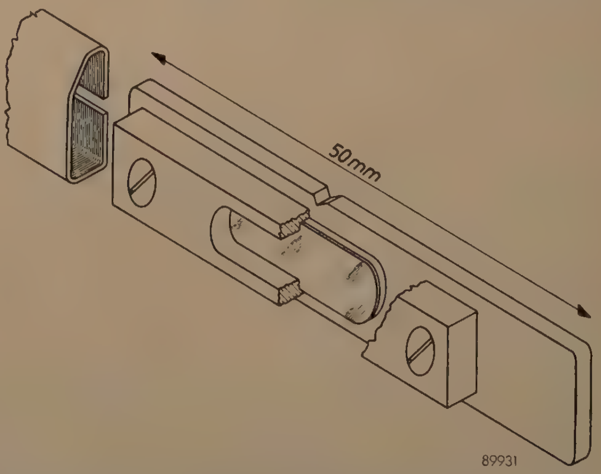

Fig. 3. Holder for nuclear X-ray source designed for location in the position of the scatter slit of the "Norelco" X-ray goniometer. To the left, part of a protective cover for the source when not in use.

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[12]) R. E. McHenry (Oak Ridge National Laboratory), unpublished report, Dec. 29, 1954.

[13]) G. E. Platzer and C. R. Lewis (Chrysler Corp., Detroit, Mich.), private communication.

[14]) Of course, the radioactively contaminated washing water must be collected and safely disposed of. We do not dwell on these and similar protective measures that have to be taken in order to safeguard the operators and surroundings in all procedures for preparing nuclear X-ray sources. It may, however, be mentioned that such measures are relatively few and easy in the electroplating method, since intermediate manipulation and processing of the material is not required.

equipment in which the source is to be used. General requirements are easy portability, adequate shielding during use and storage and a design such as to prevent the dispersal of the active material within or outside the holder. For many laboratory applications a long-handled holder with a remote control shutter mechanism has proved very useful. For users of the "Norelco" equipment for X-ray diffractometry and X-ray spectrochemical analysis [15]) the holder shown in *fig. 3* will be of foremost interest. In this holder, the source is mounted on a brass strip that can be located in the position of the scatter slit of the "Norelco" goniometer, i.e. immediately in front of and at an accurately reproducible distance from the X-ray detector (Geiger counter, proportional counter, scintillation counter), as shown in *fig. 4*.

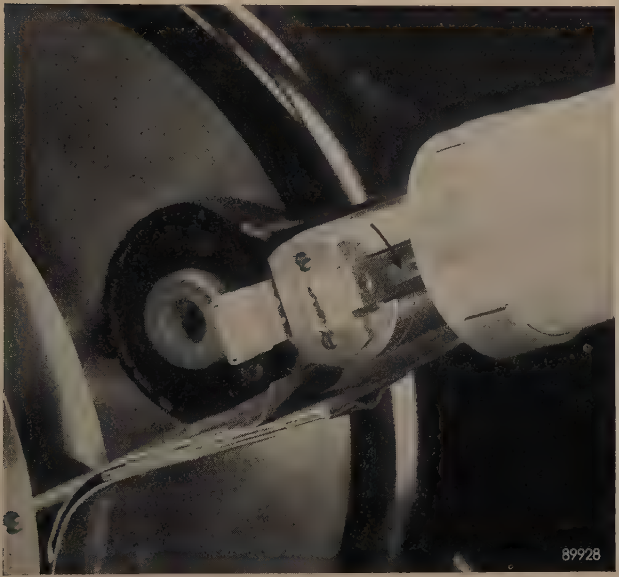

Fig. 4. Detector carrying arm of "Norelco" X-ray goniometer showing the detector to the right and the source of fig. 3 in position in the scatter-slit holder (arrow).

Applications

Sources as shown in fig. 3 have been extensively used in our laboratories for checking the stability of the complete detecting system of the above-mentioned "Norelco" equipment. The nuclear source by virtue of its ideal stability is a very effective auxiliary for testing and singling out causes of instability in such equipment. Owing to the 3 year half-life of Fe^{55}, its radiation output shows a fractional decrease of only 0.07% per day, which moreover can be easily corrected for, since the fractional disintegration rate is constant and accurately known. Output fluctuations due to the statistical nature of the photon emission processes are low enough, with the high intensity source described, to preclude difficulties in this application.

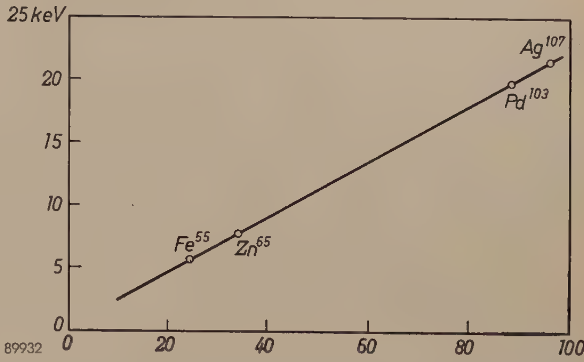

Fig. 5. Calibration of proportional counter. The photon energy (in keV) is plotted against the mean pulse amplitude (in volts), using four points corresponding to the radiation of the nuclides Fe^{55}, Zn^{65}, Pd^{103} and Ag^{107}.

The monochromatic emissions of nuclear X-ray sources, such as Fe^{55} and Zn^{65}, have made them very useful for checking the proportionality between pulse amplitude and photon energy in the proportional and scintillation counter. At the same time a calibration of the counter enabling the identification of quanta from measured pulse amplitudes is obtained (*fig. 5*), and recordings can be made of the pulse amplitude distribution curve (*fig. 6a, b*) on which depends the discrimination ability of the counter [3]). The degree of linearity of the relation between counting rate and irradiation intensity, and the "plateau" characteristic of Geiger and proportional counters are other characteristics of counters which can be easily tested with the aid of a nuclear X-ray source.

All these tests, using nuclear sources, are performed during the actual manufacture of "Norelco" radiation detectors [3]). Thus proportional counters are checked before being sealed off, and the total gas pressure is adjusted so as to give a specified pulse amplitude at a given operating voltage on irradiation with a Fe^{55} source. The components of scintillation detectors, i.e. the crystal and the photomultiplier tube, are tested separately on the work bench. Finally, life-tests of groups of detectors at high counting rates are effected by means of a number of Fe^{55} sources, thus avoiding the tying-up of costly X-ray tube equipment for long periods.

The applications of nuclear X-ray sources so far mentioned are concerned with the testing of detectors. Applications in other fields, especially those in which monochromatic radiations are required, have been considered or tried out already. X-rays

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[15]) Philips tech. Rev. **16**, 123-133, 1954/55; **17**, 269-286, 1955/56.

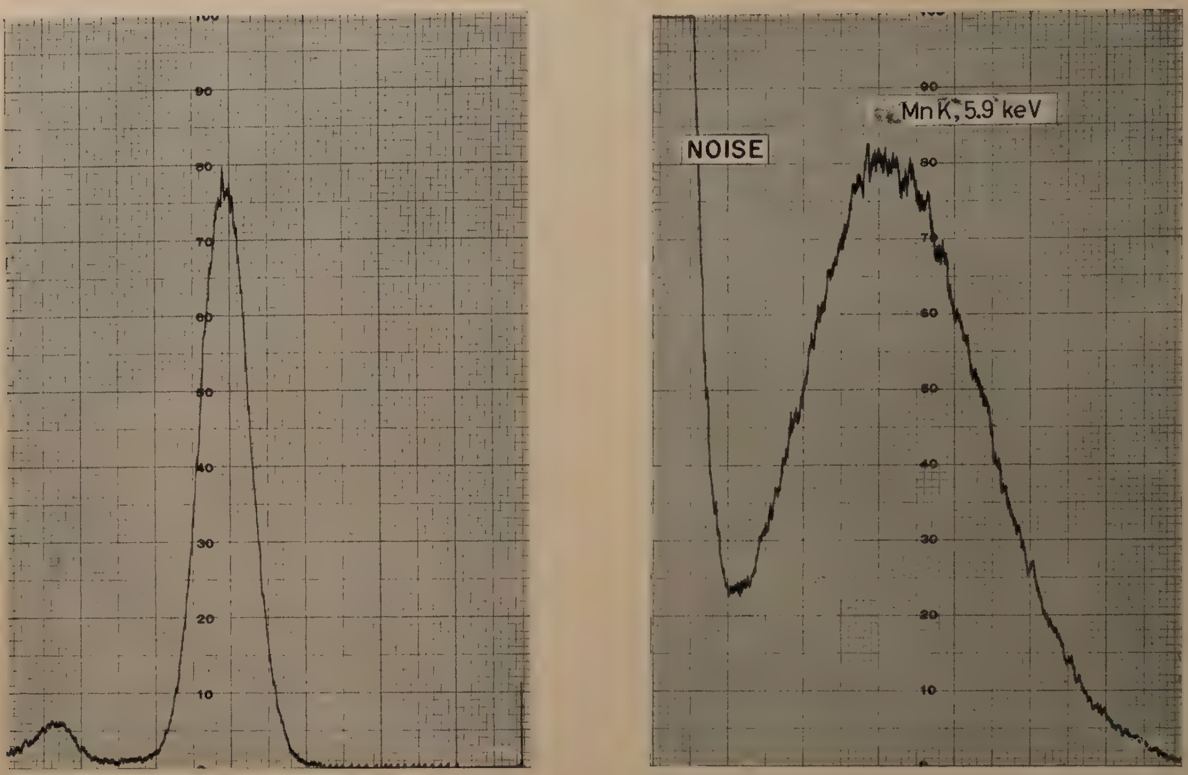

Fig. 6. *a*) Pulse amplitude distribution of a proportional counter irradiated with Mn Kα rays from an Fe^{55} source.
b) The same for a scintillation counter.
The curves were obtained with a pulse height analyzer channel width (ΔV) of $^1/_{10}$ of the half-width of the peak (cf. [3]); the number of pulses transmitted via the different channels were directly recorded over the corresponding channel position (pulse amplitude).

from radioactive nuclides have been used as wavelength standards[16]); absorption measurements of the emission of two adjacent nuclides have been proposed for quantitative analysis of an element having an absorption edge in the same wavelength region[17]); absorption analysis of sulfur in hydrocarbons has been accomplished with MnKα radiation from a Fe^{55} source [18]). Application of radionuclides such as Tm^{170} (thulium) emitting photons of energy 50 and 80 keV have been described, e.g. for inspection in industry and for emergency medical radiography [2]) [19]). Thickness gauging is another possible application in industry. Further work in the development of nuclear X-ray sources is warranted in order to broaden the field of application of X-rays by simple, inexpensive techniques for cases where the very high photon flux densities of X-ray tubes are not required.

Summary. A number of artificial radioactive nuclides emit photons of energy less than 100 keV, i.e. of wavelength longer than 0.15 Å (relatively soft X-rays). Such nuclear X-ray emitters owing to their high stability, monochromatic emission and low cost provide excellent means for testing X-ray counter tubes (especially proportional and scintillation counters), both during manufacture and in operation. After a discussion of the underlying mechanisms of the X-ray emissions, a survey of X-ray emitting nuclides with their main characteristics is given, and some techniques for preparing practically usable sources from these nuclides are described. The theoretically attainable photon flux density of Fe^{55} would provide a counting rate of nearly 10^6 counts/sec in the envisaged application; the best practical Fe^{55}-sources prepared in the Philips Laboratories attain about 10% of this value, which is amply sufficient. Fe^{55}, Zn^{65} and other X-ray sources made in these laboratories have for some time been used for testing the stability of the detection system of "Norelco" X-ray goniometers, for checking and calibrating the photon energy proportionality, the pulse amplitude distribution, the counting-rate linearity and the plateau characteristics of "Norelco" proportional and scintillation counters, for life-testing these counters etc.

Nuclear X-ray sources cannot compete on equal terms with X-ray tubes, whose useful photon flux densities may be 10^8 or in some cases 10^{10} times higher; nevertheless, they may be important for a broad and diverse field of applications in which monochromatic emissions are desired and high flux densities are not necessary.

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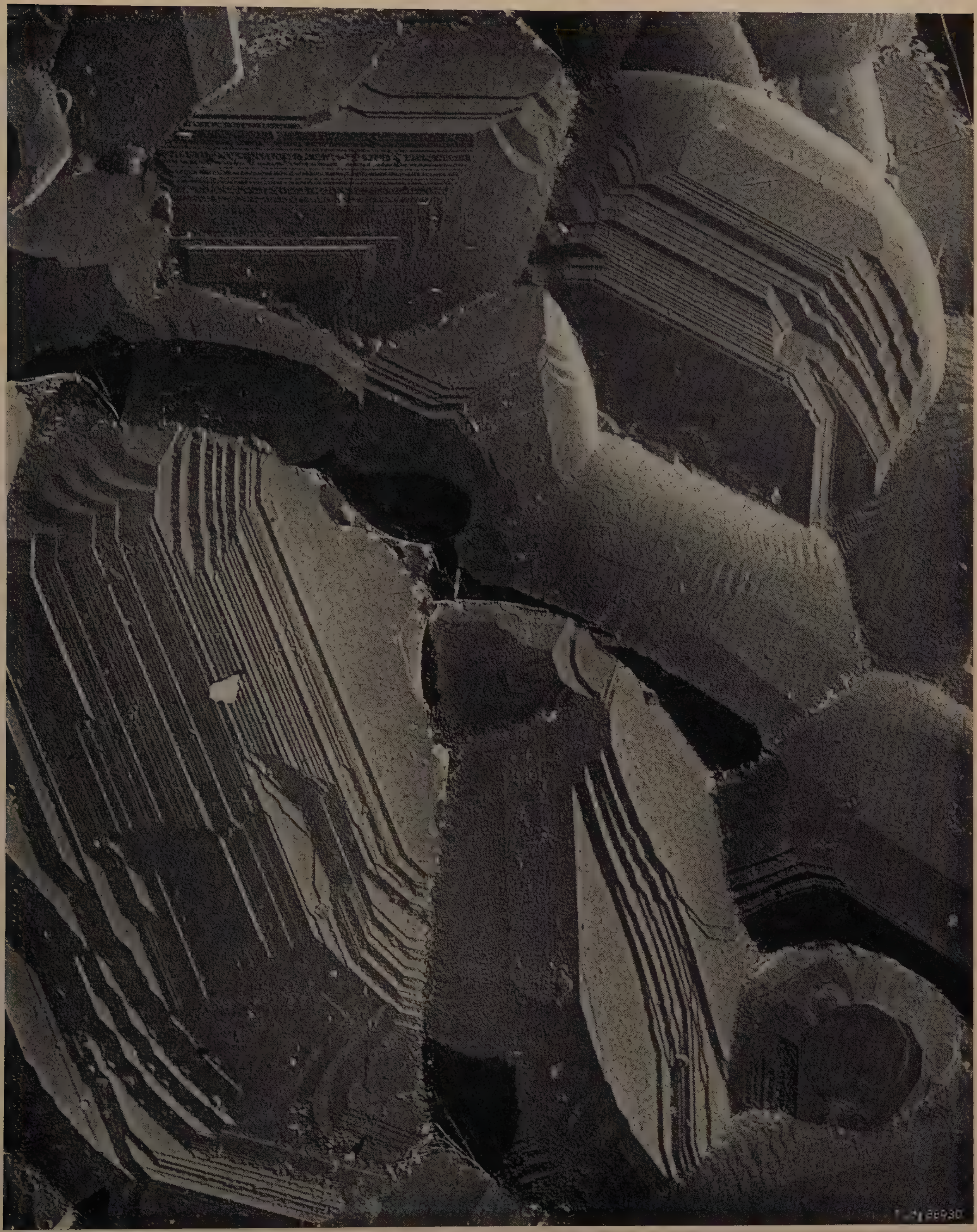
[16]) Ph. Snelgrove, J. El-Hussaini and J. W. M. DuMond, Phys. Rev. **95**, 1203-1204, 1954.

[17]) Suggested by H. A. Liebhafsky, in paper presented at Pittsburgh Conf. on Anal. Chem. and Appl. Spectroscopy, March 1955.

[18]) H. K. Hughes and J. W. Wilczewski, Anal. Chem. **26**, 1889-1893 1954.

[19]) S. Untermyer et al., Nucleonics **12**, No. 5, May 1954, pp. 35-37; R. Halmshaw, Brit. J. appl. Phys. **6**, 8-10, 1955.

ELECTRON MICROSCOPE PHOTOGRAPH OF FERROXDURE



Surface of a block of ferroxdure containing a slight excess of BaO, sintered at 1200 °C, sawn through and then reheated to a somewhat higher temperature. Photographs such as this can provide information on diffusion and grain growth in the process of recrystallization.

The photograph was made with a carbon replica (shadowed with palladium), i.e. a carbon skin evaporated on to a polystyrene impression prepared from the unpolished surface of the ferroxdure. The photograph was taken with an electron microscope EM 75 kV with an anastigmat lens 1). Magnification 23 000×.

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1) Philips tech. Rev. **17**, 47-59, 1955/56. The anastigmat developed for this microscope, which improves the resolving power to about 25 Å, will be described later in this Review.

A TRANSISTOR PRE-AMPLIFIER FOR THE MAGNETODYNAMIC PICK-UP

by C. HUBER and J. RODRIGUES de MIRANDA.

621.375.4:681.84.081.48

The new, magnetodynamic pick-up [1]) *requires a pre-amplifier if it is to be used in combination with the low-frequency section of a radio set. By employing a transistor the authors have succeeded in housing the pre-amplifier, complete with its supply unit, in a box about* $3\frac{1}{2}'' \times 3'' \times 2''$.

A new pick-up (type AG 3020/21) working on the magnetodynamic principle, has recently been marketed and has been the subject of two articles in this journal [1]). It may be recalled that this pick-up employs a ferroxdure magnet in the form of a thin rod, magnetized at right-angles to its axis and mounted so as to be able to rotate about its axis, between the ends of a magnetically conducting yoke carrying two coils. The vibrationsof the needle are converted, via a lever (the needle arm), into a turning movement of the magnet about its axis. This movement sets up an alternating flux in the yoke, which induces an alternating voltage in the coils.

The magnetodynamic pick-up is of such a quality that it can compete with electrodynamic pick-ups, which have hitherto generally been used for professional purposes. On the other hand its price is not so high as to prohibit its use in non-professional record players. In the latter case the pick-up will often be used in conjunction with a radio set, as is commonly the case with piezo-electric pick-ups. There are, however, two reasons why direct connection of the magnetodynamic pickup to an ordinary radio would not give satisfactory results. Firstly, it is less sensitive, so that an extra amplification stage is necessary. Secondly, the voltage delivered is proportional not to the amplitude, as in the case of the piezo-electric pick-up, but to the velocity of the needle point. This difference necessitates an electrical correction, which can be applied in the extra amplification stage.

Some correction is necessary even with the piezo-electric pick-up. Often this is nothing more than a very rough correction by means of mechanical resonances in the pick-up system. The better pick-ups, such as the type AG 3015 piezo-electric pick-up and the magnetodynamic pick-up, demand a more accurate correction, which it is practically impossible to obtain otherwise than electrically.

It is desirable that the extra amplification stage (pre-amplifier incorporating correction devices) be easily interposed between the magnetodynamic pick-up and a normal radio; it should therefore preferably be small and unobtrusive. Still more important, it should include its own supply unit, in order to avoid the complication of drawing the supply from the radio.

Adequate amplification could easily be attained with one valve, e.g. a double triode, but transistors are much more convenient for the present purpose: they are smaller than valves, have no filament, and require less D.C. power. This power can then easily be supplied by the mains via a germanium diode, which compared with a rectifying valve has the same advantages which transistors have over amplifying valves, viz. it is smaller in size and has no filament.

One transistor is found to be adequate. The complete circuit — the signal current and direct current parts of which will be examined separately later in the article — is shown in *fig. 1*. It will be observed that the transistor *T* is used in the circuit with a common emitter, in which the base forms the input electrode and the collector the output electrode. The pre-amplifier (type AG 9005) in its box, is shown in *fig. 2*.

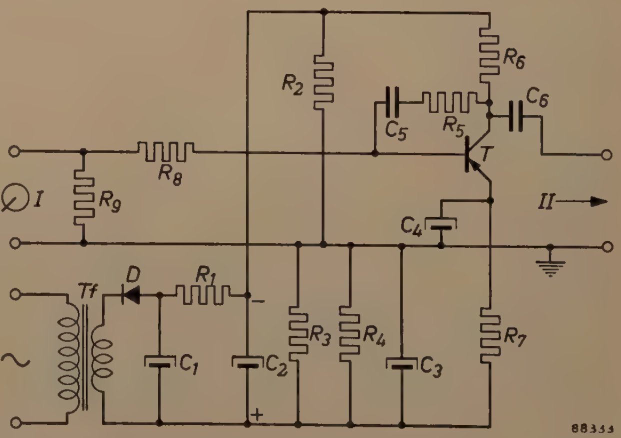

Fig. 1. Circuit of the pre-amplifier type AG 9005. The input terminals *I* are connected to a magnetodynamic pick-up AG 3020 or AG 3021, the output terminals *II* to the pick-up terminals of a radio set. *T* junction transistor OC 73. *Tf* supply transformer. *D* germanium diode OA 81. C_1-R_1-C_2 smoothing circuit. C_3, C_4 decoupling capacitors. C_6 coupling capacitor. For the significance of the other letters, see fig. 4 and fig. 6.

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[1]) N. Wittenberg, A magnetodynamic gramophone pick-up: I. Construction, II. Frequency characteristics, Philips tech. Rev. **18**, 101-109 and 173-178, 1956/57.

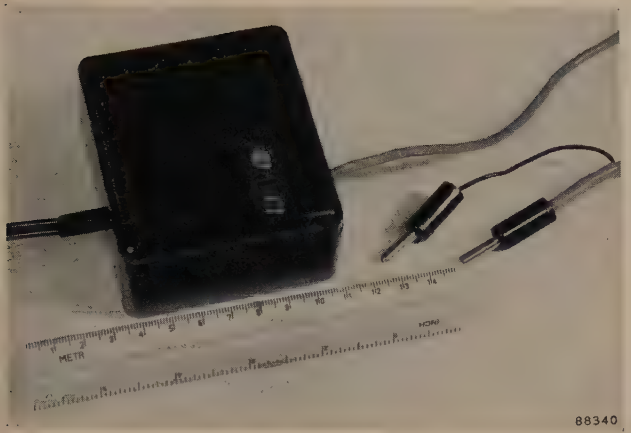

Fig. 2. External appearance of the pre-amplifier (with power unit) type AG 9005. Approximate dimensions: base $3^1/_2'' \times 3''$, height 2″.

Frequency characteristic

For most gramophone records the recording curve is of the type shown by B in *fig. 3*. This "New Orthophonic" curve, as it is called, gives the peak stylus velocity $\hat{v}$ with which the groove is cut in the lacquer disc during recording [2]) as a function of the frequency f on a logarithmic scale. B is the mirror image of the "standard response" curve A with respect to the level at 1 kc/s; the "standard response" curve gives the output voltage E as a function of f of a certain reproducing channel proposed as a standard for gramophone reproduction, the needle point of the pick-up having a constant peak velocity. With the magnetodynamic pick-up, the induced e.m.f. is proportional to the velocity of the needle point and thus (if the pick-up is assumed to be perfect) to the velocity of the cutting stylus. The amplifier used with the magnetodynamic pick-up must, therefore, have a frequency characteristic which approximates as closely as possible to the standard response curve A. In the case in question, it is the characteristic of the *pre-amplifier* which must conform to the curve A, since the remaining part of the reproduction channel (i.e. the low-frequency section of the radio) is designed for signals which are independent of the frequency. Frequencies above 1 kc/s must therefore be amplified by the pre-amplifier to a lesser extent than the frequencies below 1 kc/s.

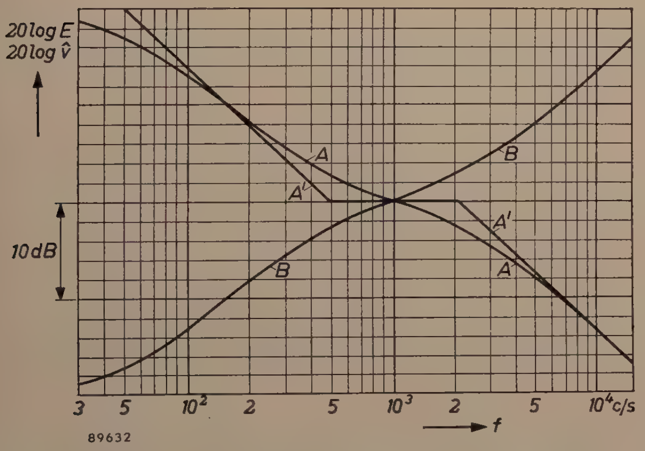

Fig. 3. A American "Standard Response" curve. B "New Orthophonic" recording characteristic. A' schematic approximation to curve A.

A good approximation to the desired characteristic has been obtained by means of two provisions: 1) a negative feedback link R_5-C_5 between the collector and the base, and 2) a resistor R_8 in series with the pick-up (see *fig. 4*, which shows only the signal current section of fig. 1; the pick-up is now represented as a generator of e.m.f. E_i, self-induction L_i and internal resistance R_i).

To illustrate the effect of these measures, consider now in fig. 3 the schematic curve A' in place of the standard response A. This exhibits an amplification which decreases inversely with the frequency up to 0.5 kc/s and again above 2.1 kc/s, and is constant between these two frequencies.

At frequencies $f = \omega/2\pi$ such that $1/\omega C_5 \ll R_5$, the link R_5-C_5 produces a negative feedback which is (virtually) independent of f, so that in this range the amplification (apart from other effects) is independent of f. At low frequencies, when $1/\omega C_5 \gg R_5$, on the other hand, the negative feedback increases in direct proportion to f, and consequently the amplification decreases approximately inversely with f, just as required by the left-hand side of the schematic response curve A'. The transition from the one frequency range to the other is characterized

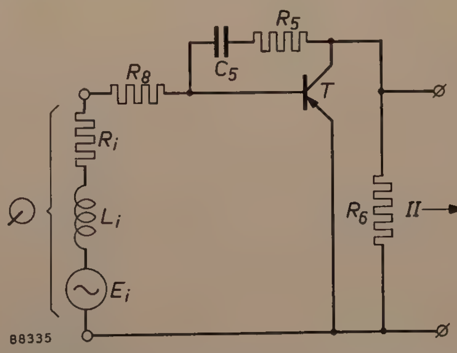

Fig. 4. The signal-carrying sections of the circuit of fig. 1. E_i-L_i-R_i equivalent circuit of the pick-up. R_8 series resistor which causes relatively smaller amplification at high frequencies. R_5-C_5 negative feedback, providing relatively greater amplification at low frequencies. T transistor OC 73. R_6 collector resistor. II output terminals.

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[2]) J. L. Ooms, The recording and production of gramophone records, Philips tech. Rev. 17, 101-109, 1955/56, particularly p. 104.

by the frequency $f_1 = 1/(2\pi R_5 C_5)$. The values of R_5 and C_5 are chosen in accordance with the response curve so that f_1 is about 0.5 kc/s.

The combination of inductance and resistance in the circuit comprising L_i, R_i, R_8 and the base-emitter resistance R_{be} has just the opposite effect. The alternating current in the base is (virtually) independent of f for frequencies $f \ll f_2 = (R_i + R_8 + R_{be})/2\pi L_i$, and is (almost) inversely proportional to f for $f \gg f_2$. If we now plot the logarithm of the base current against $\log f$, we find therefore a horizontal line for $f \ll f_2$, and a falling straight line above this frequency, corresponding to the right-hand part of the response curve. The transition frequency lies at 2.1 kc/s. The resistance R_8 is so chosen that f_2 has this value.

The result of both the above measures combined is shown in *fig. 5*, where the output voltage E_o of the pre-amplifier is plotted as a function of f, the input voltage E_i varying with f in accordance with the "New Orthophonic" recording characteristic (B in fig. 3). The variation of E_o is less than 2 dB in the frequency range from 40 to 20 000 c/s.

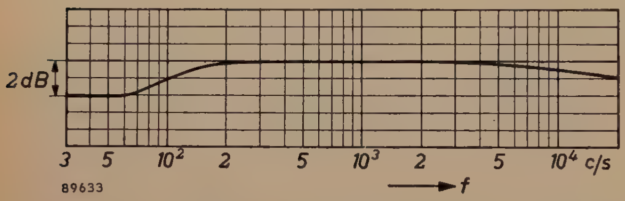

Fig. 5. Output voltage E_o on a logarithmic scale as a function of the frequency f, E_i varying with f in accordance with the characteristic B in fig. 2. External load 150 kΩ.

Data concerning sensitivity, amplification and distortion of the pre-amplifier in combination with the magnetodynamic pick-up are given in the *table* below. Certain quantities quoted in the table may be usefully defined here.

Table. Sensitivity, amplification and distortion data on the pick-up AG 3020/21 with the pre-amplifier AG 9005. External load: resistance ≧120 kΩ in parallel with a capacitance of $\leqq 10^{-9}$ F.

Frequency	60 c/s	1000 c/s	10 000 c/s	
Sensitivity	400	71.5	15.5	mV/(cm/s)
Voltage amplification	41	27	25	dB
Current amplification	21.4	7.8	5.2	dB
Insertion gain	41	25	13.6	dB
Transfer impedance	1170	230	180	mV/μA
Distortion (for maximum E_o and an ambient temperature of 20 °C)	≦1.5	≦0.4	≦2	%

Sensitivity: output voltage E_o (r.m.s. value) in mV for a peak needle velocity of 1 cm/sec.
Voltage amplification: 20 log E_o/E_i dB.
Current amplification: 20 log I_o/I_i dB (I_i = input current, I_o = output current).
Insertion gain: 20 log E_o/E_i dB, where E_i is the terminal voltage of the pick-up when the latter is loaded with its normal load resistance (68 kΩ).
Transfer impedance: E_o/I_i, in mV/μA.

Stabilization of the working point

At maximum modulation the output voltage may show peak values of 3.5 V. To avoid distortion it is necessary to ensure that the D.C. voltage $|V_{ce}|$ between collector and emitter never falls below 4V. $|V_{ce}|$ is given the rather high nominal value of 10 V, but for a number of reasons the danger that $|V_{ce}|$ might become less than 4 V is a real one: not only must mains voltage fluctuations be taken into account, but also the quite appreciable effect of the temperature, the spread in the properties of transistors and the spread in resistance values.

A new type of junction transistor [3]) has been selected, OC 73, which has been found during manufacture to have an appreciably smaller spread in properties than the older types. Resistors with a tolerance of ±2% have been specified where the accurate value of the resistance is critical.

The effect of the temperature still remains. In general, temperature has quite an appreciable effect on transistors, and the pick-up preamplifier is required to work well for all ambient temperatures from 10 to 45 °C (this higher temperature limit is stipulated since it is anticipated that the magnetodynamic pick-up will find a ready market in the tropics as it is better able to withstand tropical conditions than are other systems).

As a first step towards minimizing the effect of temperature a resistor R_7 is connected in series with the common electrode — in this case the emitter (see *fig. 6*, which shows the direct current part of the circuit in fig. 1). Just as a cathode resistor has a stabilizing action on the anode current of valves, so here R_7 (shunted by capacitors C_3 and C_4 in series, see fig. 1) has a stabilizing effect on the collector D.C. (D.C. negative feedback), and consequently on the voltage V_{ce}.

This single precaution is not enough however. In order to obtain high amplification, a high value has been chosen for the collector resistance R_6 (0.1 MΩ). Hence a slight increase in the collector current (as a result of an increase in temperature) may be sufficient to cause $|V_{ce}|$ to fall below the admissible value. For this reason, as a second stabilizing device, a thermistor (NTC resistor) R_3 with a large negative temperature coefficient [4]) has been incorporated in the potential divider $R_2 + (R_3//R_4)$ which determines the potential of the base. As a result the potential of the base is dependent on the ambient temperature in such a way that the effect of the temperature on the transistor is adequately compensated.

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[3]) For the simple theory of the junction transistor, see F. H. Stieltjes and L. J. Tummers, Philips tech. Rev. 17, 233-246, 1955/56.

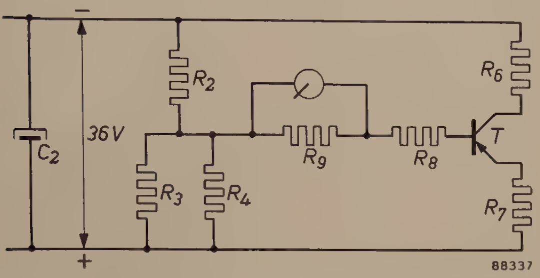

Fig. 6. The D.C. sections of the circuit of fig. 1. C_2 smoothing capacitor. $R_2+(R_3//R_4)$ voltage divider (R_3 thermistor, R_4 ordinary resistor). R_6 collector resistor. T transistor OC 73. R_7 resistor for D.C. negative feedback. R_8 series resistor (see fig. 4). R_9 resistor which limits the voltage across the transistor when the pick-up is disconnected.

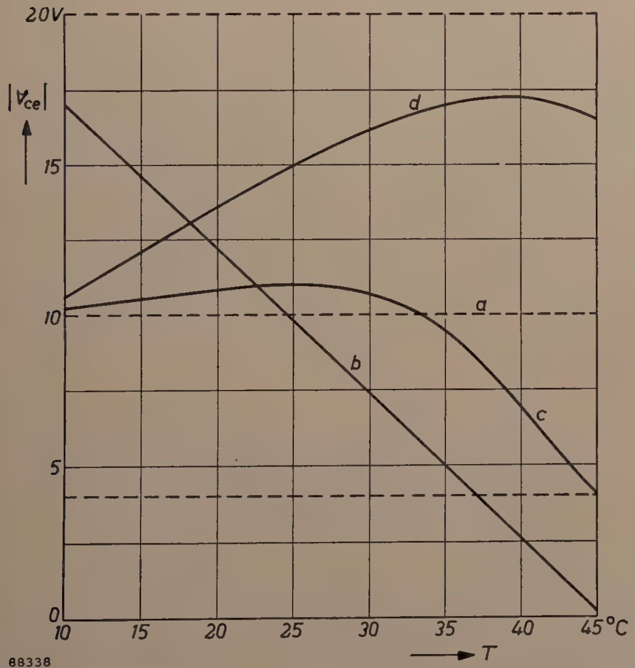

Fig. 7. Line a: constant value of 10 V at which it would be desirable to keep $|V_{ce}|$, irrespective of the ambient temperature T. Line b: variation of $|V_{ce}|$ in absence of thermistor (R_3 in fig. 6). Lines c and d: extreme values assumed by $|V_{ce}|$ (all tolerances having been taken into consideration), when an ordinary resistor (R_4) is used in parallel with a thermistor (R_3).

This compensation can be explained as follows. In *fig. 7*, a indicates the value at which it would be desirable to keep $|V_{ce}|$ constant (10 V). If there were no thermistor, $|V_{ce}|$ would depend upon the ambient temperature T as shown by line b. If $R_3//R_4$ is replaced by a variable resistor and a graph is plotted of how resistance must vary to keep $|V_{ce}| = 10$ V as T changes from 10 to 45 °C, the curve R in *fig. 8* is obtained. The variation of a thermistor with T differs considerably from curve R, as shown by curve NTC. By connecting a thermistor in parallel with an ordinary resistor, a temperature variation like $R_3//R_4$ in fig. 8 can be obtained which can be made to approximate sufficiently closely to the desired variation (R). In the case in point this is achieved by connecting a thermistor of 47 kΩ (at 25 °C) in parallel with an ordinary resistor of 20 kΩ. The extreme values of $|V_{ce}|$, found with this combination, all tolerances having been taken into consideration, are given by the curves c and d of fig. 7. It may be seen that in the temperature range from 10 to 45 °C, $|V_{ce}|$ never falls below 4 V and never exceeds 20 V (the maximum value which is permissible for the transistor).

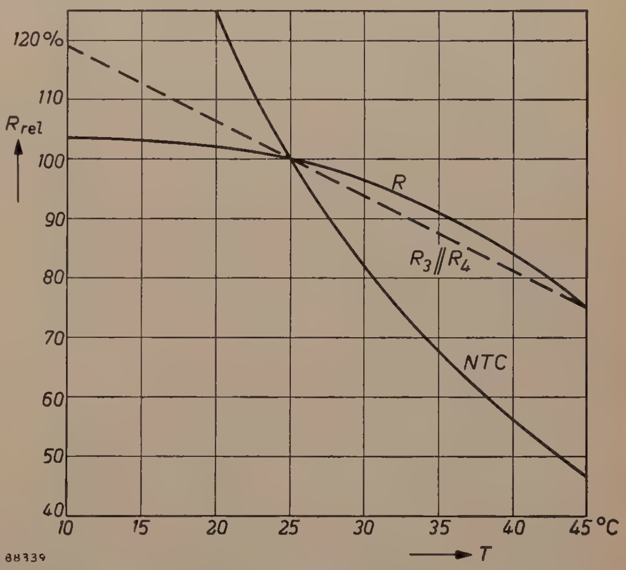

Fig. 8. R: variation of the resistance of $R_3//R_4$ in fig. 6 required if $|V_{ce}|$ is to remain equal to 10 V for T = 10 to 45 °C. NTC: variation of the resistance value of a thermistor. $R_3//R_4$ approximation to the curve R, obtained by connecting a thermistor and an ordinary resistor in parallel. (All resistance values are on a relative scale: R = 100 at 25 °C.)

Resistor R_9 (fig. 1 and fig. 6) ensures that the base circuit is not interrupted when the pick-up is being changed or disconnected and prevents too high a voltage from being applied to the transistor. The resistance of R_9 is so high (0.47 MΩ) that it has no effect when the pick-up is plugged in.

It may be noted that the D.C. base current (maximum about 50 μA) flows through the pick-up, but is quite harmless.

Power unit

The high values of $|V_{ce}|$ (nominal 10 V) and of the collector resistor R_6 necessitate a relatively high supply voltage, namely 36 V. This voltage

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[4]) E. J. W. Verwey, P. W. Haayman and F. C. Romeyn, Philips tech. Rev. 9, 239-248, 1947/48.

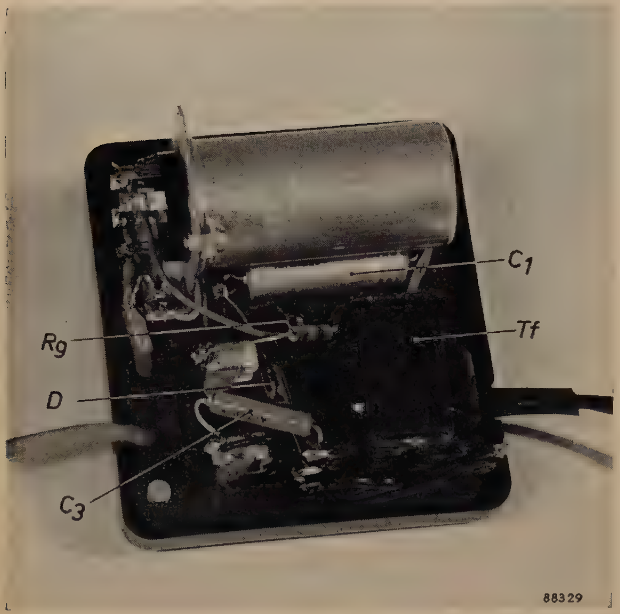

Fig. 9. The pre-amplifier AG 9005 with cover removed. The cylindrical screening can houses the pre-amplifier proper (see fig. 10). Significance of the letters as in figs. 1, 4 and 6

can be obtained by rectification with a germanium diode [5]) OA 81, the maximum peak inverse voltage of which is 115 V. With the current required here (about 0.4 mA) this diode is only carrying a fraction of its maximum permissible load.

The filter C_1-R_1-C_2 (fig. 1) smooths the rectified voltage to the extent that the extra hum produced in the loudspeaker when the pre-amplifier is switched in is barely audible. This means that the hum component in the output voltage of the pre-amplifier is less than 1.5 mV, i.e. about 65 dB below the maximum output voltage.

There is one point to be mentioned regarding the transformer. In conformity with safety requirements the supply transformers in radio sets, amplifiers, etc. are provided with a temperature-sensitive safety device which automatically cuts off the mains supply to the transformer if the latter threatens to become too hot. In the pre-amplifier under discussion, the transformer is so small that it would be difficult to fit such a safety device. Fortunately such a device is found to be unnecessary since the transformer is shortcircuit proof. In normal operation the power dissipated mainly comprises iron losses. If the secondary coil is short-circuited the copper losses of course increase, but owing to the relatively large stray inductance and resistance of the coil the increase is only small. Moreover, owing to the increased voltage drop in the primary coil, the induced e.m.f. becomes smaller, and hence the iron losses decrease. Thus in the event of a short circuit the total loss changes hardly at all, so that the transformer does not become too hot.

Mechanical construction

The pre-amplifier complete with power unit is mounted in a rectangular "Philite" box (fig. 2 and *fig. 9*), of size 86 × 78 × 49 mm (about $3^1/_2'' \times 3'' \times 2''$). The pre-amplifier proper is constructed as a self-contained unit, all its components being mounted on an insulating plate which is housed in a cylindrical screening can (*fig. 10*). The reason for this is that if future designs of radio sets and amplifiers should have the pre-amplifier power supply (36 V, 0.4 mA) already built-in, it will only be necessary to add the pre-amplifier proper as in fig. 10.

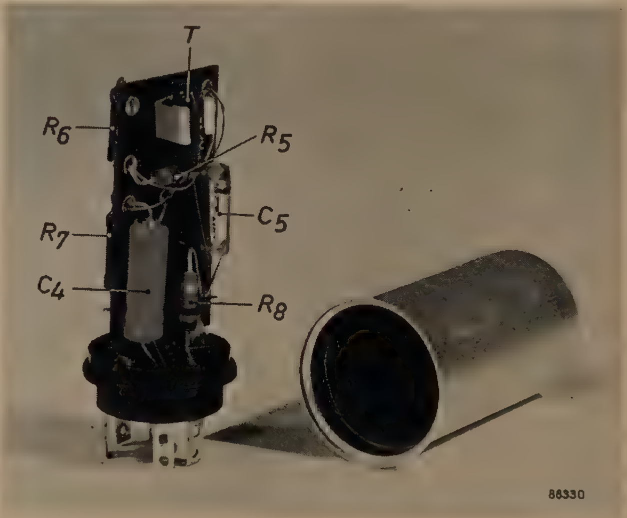

Fig. 10. The pre-amplifier proper with screening can (diameter 1 inch, length 2 inches). Significance of the letters as in figs. 1, 4 and 6.

Summary. Description of the pre-amplifier AG 9005, designed for coupling the magnetodynamic pick-up AG 3020/21 to a normal radio. Its purpose is to amplify the signal voltage to an adequate level (max 2.5 V r.m.s.) and at the same time to provide a frequency characteristic conforming to the "New Orthophonic" cutting characteristic of gramophone records. The necessary amplification is obtained with one OC 73 transistor connected with common emitter. As one of the measures taken to stabilize the working point at differing ambient temperatures (10 to 45 °C), a thermistor is incorporated. The power unit contains a transformer, a germanium diode OA 81 and a smoothing filter. The pre-amplifier proper, together with supply unit, is mounted in a box about $3^1/_2'' \times 3'' \times 2''$.

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[5]) Philips tech. Rev. **16**, 225-232, 1954/55.

A NEW KIND OF TUNING INDICATOR TUBE

621.385.832:621.317.7

Tuning indicators ("magic eyes") are employed in radio receivers and also, in bridge and balance circuits, as null-indicators for voltage comparison. The tuning indicator tubes hitherto available have the disadvantage that, generally speaking, they only show whether a voltage difference is present or not; they do not give its sign and only give a very rough idea of its magnitude.

These shortcomings have been eliminated in the E 82 M tuning indicator tube, developed in the laboratory of the Valvo radio tube factory in Hamburg[1]). In this tube an electron beam of rectangular section produces a rectangular spot on a fluorescent screen. Unlike other indicator tubes, the E 82 M has two symmetrically mounted electrodes which act as deflector plates. The voltages to be compared are applied to these electrodes either directly or via amplification stages. If the two voltages are not of equal magnitude there is deflection of the spot to one side or the other; further, the width of the spot when not deflected (i.e. when the voltages are equal) gives some indication of the value of the two voltages.

In a tube like this there must be some sort of datum to mark the position of no deflection, i.e. the central zero. The datum for the E 82 M is on the outside of the tube, in order to facilitate zero calibration, in connection with possible departures from symmetry in the electrode system or the circuit. Another reason for having the marker on the outside is to make the tube better adaptable to purposes which may require special forms of indication. The external datum mark necessitates a change in the arrangement of the fluorescent screen: this is viewed, not from the side on which the electrons strike it (as in the conventional tuning indicator), but from the side opposite to the beam. The screen is in fact coated on the inside wall of the tube, to avoid parallax errors. The datum mark may take the form of a pattern painted on the outside of the tube; alternatively, it may be a thin metal mask, cut out in any desired pattern, fitted on to the cylindrical envelope. One pattern that is suitable for many purposes appears in *fig. 1*; *fig. 2a* shows the complete tube, and fig. 2*b* a tube with the mask holder removed and four alternative mask patterns (numbered *1-4*).

Fluorescent screens on glass are nothing new; they have long been used in oscillograph and television picture tubes. In such tubes the electron accelerating potential is of the order of several thousand volts. A tuning indicator, however, must rely on the supply already available in the receiver or measuring set; thus the acceleration voltage should not be higher than, say, 250 V. At voltages as low as this the normal type of fluorescent screen acquires a considerable charge, so that further electrons are prevented from striking it, and thus it remains dark; at higher voltages, increasing secondary emission drains off the charge quickly enough for this phenomenon to be avoided[2]). Where the screen is on a metal base, as in conventional tuning indicators (where, it will be remembered, the screen is viewed from the electron beam side, not by transmission as in the present tube) this base serves to conduct the charge away, even at low voltages. In the present tube the charge is drained off by means of a very thin layer of tin oxide coated on the inside wall prior to the application of the fluorescent screen; the tin oxide is practically transparent, but it has good conducting properties, and it is to this layer that the positive acceleration potential is applied. In this way the voltage below which charge would accumulate on the screen has been reduced to about 100 V. The phosphor used is zinc oxide, which fluoresces with a bluish-green light and which, after further activation by electron bombardment, exhibits a slower decrease of brightness with age than the usual willemite.

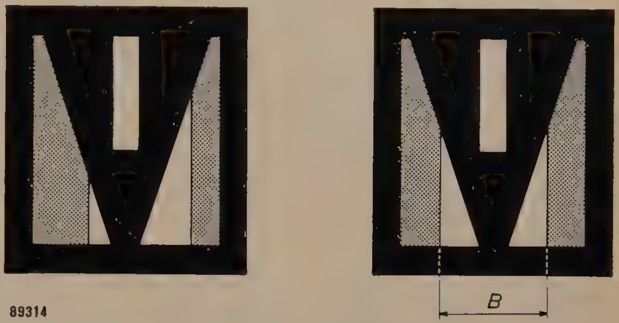

Fig. 1. Mask for the E 82 M tuning indicator. Left: appearance when tuning or adjustment is out of balance. Right: appearance when balanced. The breadth *B* of the spot (and hence also the height of the luminous triangles, when balanced) is a relative measure of the mean value of the two applied voltages.

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[1]) See also H. te Gude and E. Schaaff, Abstimmanzeigeröhren für die Messtechnik, Elektronische Rundschau **9**, 184-189, 1955.

[2]) For a detailed discussion of these phenomena, see for example, J. de Gier, A. C. Kleisma and J. Peper, Secondary emission from the screen of a picture-tube, Philips tech. Rev. **16**, 26-32, 1954/55.

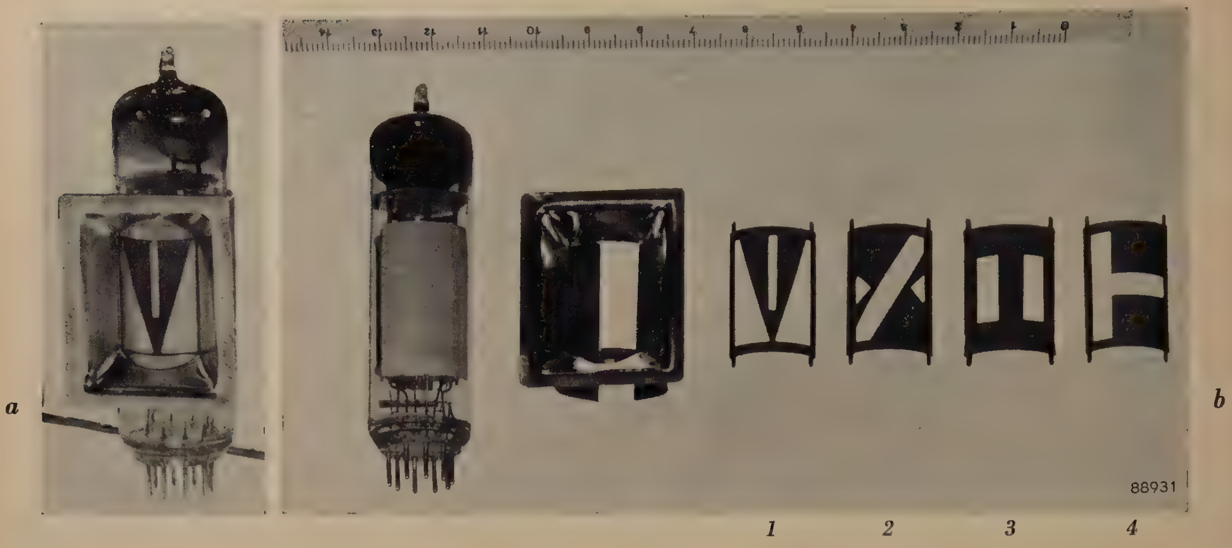

Fig. 2. *a*) E 82 M indicator tube fitted with mask in holder. *b*) Tube, mask holder and (*1-4*) various types of masks.

In order that the tube should have greater deflection sensitivity, a stage of amplification for each of the two voltages to be compared is incorporated within the same envelope. Each of the voltages is applied to the grid of a triode that acts as a voltage amplifier; the anodes of these two triode systems at the same time function as deflector plates for the indicator section of the tube. The actual electrode arrangement is shown in *fig. 3*.

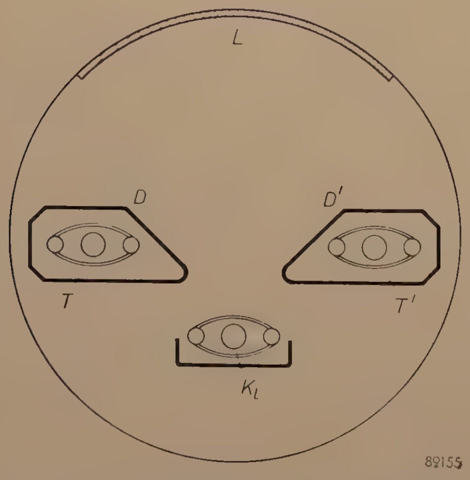

Fig. 3. Cross-section of the E 82 M tube. K_L: cathode of indicator section providing electrons for rectangular beam. L fluorescent screen. D and D': deflector plates, which also form the anodes of the triode sections T and T'.

The characteristics of the two triode systems must, of course, be exactly the same within the operating range; differences of slope due to changes in the working point would have the same effect as a difference between the voltages to be compared. To ensure exact symmetry in this sense, the characteristics of the triode sections of the E 82 M are made as straight as possible. It would hardly be possible to manufacture the tube without troublesome departures from symmetry if its characteristics were curved, as they are in many conventional tuning indicators, which have variable-mu characteristics in order to extend the range of voltages that may be compared. The E 82 M can also be given a wide measuring range, however, in spite of its straight-line characteristics, and this is achieved in the following way. The two triode systems are each provided with a separate anode resistor, while they share a common cathode resistor. The cathode resistor and the cathode bias voltage are both relatively large so that the negative bias then effective on the grid of each triode changes in the same sense and by approximately te same amount as changes in the mean value of the two voltages to be compared. This produces a beam-width versus mean-voltage characteristic, the working region of which, though roughly straight, has a smaller slope than it would have in the absence of the cathode resistor. The beam width thus gives a less sensitive indication of the mean value of the two applied grid voltages, which means that the operating range is increased and moreover this range can be varied during operation. Whatever the magnitude (within certain limits) of the applied voltages, their *difference* is always indicated in full. In order to permit the range adjustment facility for the mean voltage, the cathodes of the two triode sections are taken to a separate pin from that of the cathode of the indicator section.

Apart from its obvious uses, particularly as a null indicator in bridge circuits, where indication of the sign of the unbalance is of great value especially in the choice of the correct measuring range, the E 82 M can be used for a number of different purposes. The two triodes can be made to function as a multivibrator in a flip-flop (scale of two) counter circuit, a suitable mask pattern (*3* in fig. 2) being fitted to give indication of the counting state. Fitted with another mask pattern such as *2* or *4* in fig. 2, the tube becomes suitable (as are conventional tuning indicators) for giving a check on modulation depth in tape-recorders and the like. Mention may also be made of the use of the tube (with mask *1* in fig. 2) as a tuning indicator for FM receivers, and for voltage measurement with a suppressed zero level (alarm circuits set off by the deviation of the unknown voltage from a standard comparison voltage).

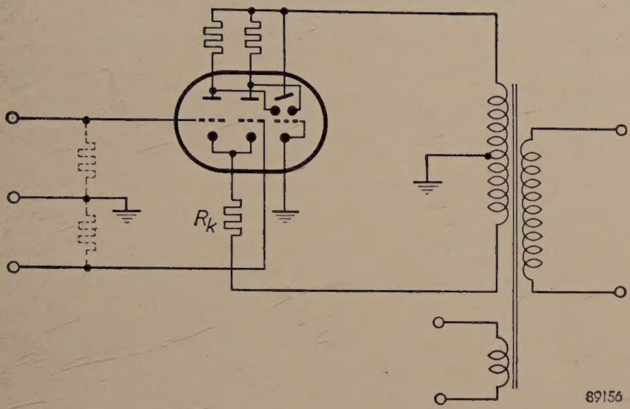

Fig. 4. Null-balance indicating circuit using the E 82 M, the tube being operated entirely on A.C.

In these and other applications it is sometimes a great advantage that the E 82 M may be operated entirely on alternating voltages. Periodical variation of the voltage on the deflector electrodes does no harm, provided only that this voltage remains proportional to that on the fluorescent screen, and this is automatically the case when the amplifying sections are fed from the same alternating voltage as the fluorescent screen anode. It should be noted that when using the range adjustment facility described above, the bias voltage on the common cathode resistor R_k must be in opposite phase to the voltage on the screen (see *fig. 4*).

H. te GUDE*) and E. SCHAAFF*).

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*) Development laboratory, Valvo G.m.b.H. Radioröhrenfabrik, Hamburg.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS BY THE STAFF OF N.V. PHILIPS' GLOEILAMPENFABRIEKEN

Reprints of these papers not marked with an asterisk * can be obtained free of charge upon application to Philips Electrical Ltd., Century House, Shaftesbury Avenue, London W.C. 2.

2357: R. Vermeulen: Music reproduction (T. Ned. Radiogenootschap **21**, 39-41, 1956).

Short description of subjective experiments on the reproduction of music and the use of artificial stereo-reverberation (see also Philips tech. Rev. **17**, 171-177 and 258-266, 1955/56).

2358: G. Diemer and W. Hoogenstraaten: Evidence for hole-mobility in CdS (Physica **22**, 172, 1956).

Measurements of the photoconduction under local illumination have been carried out on single crystals of CdS. When illuminated between graphite electrodes by a narrow line of ultraviolet (3650 Å, width about 0.5 mm, i.e. $^1/_{20}$ of inter-electrode distance), these crystals show an increase of the current, at 250 volts D.C., by a factor of 20. This increase of the conductivity can be explained only if the space charge of the conducting free electrons in the dark part of the crystal is compensated by a nearly equal quantity of positive holes, which must therefore be assumed to migrate from the illuminated part through the whole inter-electrode space.

2359: D. de Nobel and D. Hofman: The dielectric constant of CdTe (Physica **22**, 252, 1956).

The dielectric constant of CdTe was determined at 20 °K and 77 °K at frequencies varying from 1 to 100 kc/s with a bridge of the Schering type. The dielectric constant is found to be approximately 11.

2360*: J. Volger, J. M. Stevels and C. van Amerongen: Les pertes diélectriques de divers "monocristaux" de quartz aux très basses températures (Verres et Réfractaires **10**, 3-14, 1956).

Translation into French of **R 272**.

2361: A. van Weel: Récepteurs de télévision à phase linéaire (Onde Electrique **36**, 48-56, 1956).

The author shows that it is possible, without complicated circuitry, to design an I.F. amplifier with only a very small phase distortion yet fulfilling the normal requirements for television receivers. The same subject is dealt with in Philips Res. Rep. (see **R 273** of these abstracts).

2362: J. Smit: Galvanomagnetic properties of ferromagnetic metals and alloys (Dissertation, Leiden, 11 April 1956).

A number of measurements and theoretical work by the author are here collected together. In chapter I the band structure of incomplete shell electrons 3d and 4s in nickel is calculated, taking into account correlation. Chapter 2 gives experimental results for the Hall effect in ferromagnetic metals and alloys and a theoretical discussion on the origin of the spontaneous part. It is shown that in a perfectly periodic lattice the spontaneous Hall effect cannot occur. The explanation is to be found in anisotropic scattering of the conduction electrons at lattice faults, due to spin-orbit interaction. This is worked out numerically with the aid of a simple model. Chapter 3 deals with the magnetoresistance of ferromagnetics. Resistance anisotropy is explained on the basis of ellipsoidal charge distribution of the core electrons caused by spin-orbit interaction. This is discussed quantitatively (see also these abstracts Nos. **1996** and **2319**).

2363: N. W. H. Addink: Bestimmung von Spurenelementen (ohne chemische Vorbehandlung) und Analyse kleinster Materialmengen mittels spektrochemischer Methoden (Mikrochimica Acta, No. 1-3, 1956, pp. 299-303). (Estimation of trace elements, without chemical pre-treatment, and analysis of very small amounts of material by spectrochemical methods; in German.)

The lowest limits of detection of several trace elements are given for spectrochemical and microchemical determinations. There is a relationship between the lowest limits of detection as determined by spectrochemical procedures at various temperatures. Some figures regarding the minimal amount of the sample are given.

2364: A. L. Stuijts: Sintering of ceramic permanent magnetic material (Trans. Brit. Cer. Soc. **55**, 57-74, 1956).

The permanent magnetic properties of the hexagonal compound $BaFe_{12}O_{19}$ are described. To achieve the best magnetic values the product should have a high apparent density and consist of particles with a diameter of the order of 1 μ. Sintering of a non-stoichiometric composition is favourable for obtaining high densities. In order to keep the crystallites as small as possible, a high rate of heating up and a short time at the highest temperature are desirable.

In sintering, two different types of crystal growth are observed: a continuous and a discontinuous one. In the latter case, an explanation may be found in the presence of a second phase. A considerable improvement in magnetic properties can be obtained by lining up the hexagonal axes of the component crystallites. In practice this can be achieved by pressing a paste of the powder in a magnetic field. Crystal growth during sintering enhances the magnetic anisotropy of the material considerably.

2365: J. S. C. Wessels and R. van der Veen: The action of some derivatives of phenylurethan and of 3-phenyl-1,1-dimethylurea on the Hill reaction (Biochim. et biophys. Acta **19**, 548-549, 1956).

The action of some derivatives of phenylurethan and of 3-phenyl-1,1-dimethylurea on the Hill reaction was investigated. 3-phenyl-1,1-dimethylurea derivatives inhibit the Hill reaction at lower concentrations than derivatives of phenylurethan. The inhibitory activity is enhanced by introduction of electron-attracting groups into the benzene nucleus. A possible explanation of the experimental results is presented.

2366: J. J. Balder: Verfärbung farbiger Objekte durch die Einwirkung von Tageslicht, Glühlampenlicht und Leuchtstofflampenlicht (Lichttechnik **8**, 57-81, 1956). (Discoloration of coloured objects under the influence of daylight, incandescent light and fluorescent light; in German.)

The discoloration of a number of coloured objects by various types of light was investigated. Four specimens of each object were exposed to four types of light: daylight filtered through window glass, incandescent lamp light, and light from tubular fluorescent lamps "White-de-luxe" and "Warm-white-de-luxe". The dose of light administered was in all cases 8 Mluxh. The discolorations were judged visually by three persons. This method could be justified by colorimetric measurements. Daylight through window glass had the worst discolouring effect, followed by fluorescent lighting White-de-luxe and then incandescent lighting, while fluorescent lamps type Warm-white-de-luxe gave least discoloration.

2367*: J. Hermsen, A. M. J. Jaspers, P. Kraayeveld and K. van Duuren: New Geiger tube designs, hollow anode and parallel plate counters. (Proc. Int. Conf. Peaceful uses Atomic Energy, Geneva, Aug. 1955, Vol. 14, pp. 275-276, New York 1956).

Short notice concerning some Geiger counters of unusual geometry. One type has a tubular anode (internal diameter 23 mm) in place of the usual wire; the sample may be placed within this tube. Another type has parallel plate electrodes. The properties of these counters are given in the form of graphs.

2368: J. A. Kok: Experiments with gas-filled triodes (Appl. sci. Res. **B 5**, 445-453, 1956).

In this paper experiments are described showing the different types of electrical discharges in a gas-filled triode. The determining parameters are the following: the cathode emission, the spacing of cathode, grid and anode, the diameter of the meshes of the grid, the potentials of the grid and the anode, the gas pressure and the differential ionization function of the gas. The anode voltage may be concentrated in a space-charge sheath. If this space-charge sheath is located at the grid, the anode current may be modulated with moderate grid potentials. If not, much larger voltages are required for modulation.

2369: K. H. Klaassens and C. J. Schoot: Some fluoro-substituted phenoxyacetic acids (Rec. trav. chim. Pays-Bas **75**, 186-189, 1956).

The preparation of 2,4-dichloro-6-fluorophenoxyacetic acid, 2,4-dichloro-3-fluorophenoxyacetic acid and 2,4-dichloro-5-fluorophenoxyacetic acid is described.

2370: C. J. Schoot and K. H. Klaassens: 5,7-dichlorocoumaran-3-one (Rec. trav. chim. Pays-Bas **75**, 190-192, 1956).

The preparation of 5,7-dichlorocoumaran-3-one is described.

2371: J. F. Klinkhamer: Reflectionless transmission through $2n$-terminal-pair networks (Proc. Symp. Mod. Network Synthesis, Polytechnic Inst. Brooklyn, April 1955).

Various authors have treated $2n$-poles by a generalization of corresponding considerations of 2-poles. In such cases current and voltage vectors take the place of the scalar currents and voltages of the 2-pole case, while impedance matrices take the place of the normal scalar impedances. In a similar way, in this article, by a generalization of considerations of a 4-pole chain, a "mirror-impedance" and a "transmission constant" are defined in matrix form for a chain of $4n$-poles. Both matrices, for positive values of the real part of the frequency parameter, are unambiguously determined. The eigen vectors of the transmission matrix can be considered as independent travelling waves, each with its own damping and phase shift.

2372: C. Z. van Doorn and D. de Nobel: Luminescence, transmission and width of the energy gap of CdTe single crystals (Physica **22**, 338-342, 1956).

Irradiation of a CdTe single crystal or biasing a CdTe p-n junction in the forward direction lead to a luminescence with a maximum at about 8880 Å. From transmission measurements and measurements of the long wave limit of the photo-e.m.f. of a CdTe p-n junction as a function of the temperature, the shift of the band edge was seen to vary from 2.34×10^{-4} eV/°K at 77 °K to 5.44×10^{-4} eV/°K at 800 °K.

2373: J. L. Ouweltjes and W. L. Wanmaker: Contributions to the problem of nonstoichiometry in oxygen-dominated phosphors (J. Electrochem. Soc. **103**, 160-165, 1956).

According to general experience, oxygen-dominated phosphors of highest efficiencies are obtained with non-stoichiometric compositions. This has been explained by the hypothesis that crystal defects are essential to obtain luminescence. In this paper it is postulated that the ideal, and therefore stoichiometric crystal should have maximum efficiency. That an excess of one of the ingredients in general results in higher efficiency, is explained with certain factors arising from the mechanism of the solid-state reactions, such as the difficulty of reaching equilibrium conditions. The incorporation of the activator, the presence of U.V. absorbing separate phases, the problem of homogeneity of the phosphors, and the reactivity of the ingredients used for the synthesis are discussed, mainly on the basis of experimental evidence gathered in the study of the phosphors used in fluorescent lamps.

R 298: P. Zalm: The electroluminescence of ZnS type phosphors (Philips Res. Rep. **11**, 353-399, 1956).

First part of a paper dealing with various aspects of the electroluminescence of ZnS (Destriau effect). Section 1 gives a brief survey of the theories of photoluminescence in ZnS, in so far as these are of consequence for electroluminescence. Various methods of preparation of electroluminescent ZnS powders are treated in section 2. Section 3 deals with electrical and optical measurements which have led to a qualitative model with which the mechanism of electroluminescence can be explained. A distinction must be made between phosphors where excitation by the field causes ionization of the activators, and those where this does not happen. In the latter case the light emission is virtually in phase with the voltage; in the former case, electrical factors cause a shift over a substantial fraction of the period of the field between the moments of maximum excitation and of maximum emission. In experiments with hexagonal single ZnS crystals activated by Cu it was found that the mechanism of electroluminescence does not differ essentially from that of powders. In single crystals the excitation occurs at the internal barriers, which have rectifying properties. A relationship is established between the orientation of the barriers at which light emission occurs and that of the crystal axes. For the second part of this paper, see **R 300**.

R 299: M. J. Sparnaay: On thermal hysteresis of transformations in solids (Philips Res. Rep. **11**, 400-409, 1956).

A simple order-disorder theory for the qualitative understanding of hysteresis phenomena is discussed. The essential feature is the introduction of an element of asymmetry into a zeroth-order treatment.